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November 1989 A Cahners Publication

R&D
Research & Development

How they built Thermo Electron into 'a perpetual idea machine'

COMPUTERS

Molecular dynamics on a desktop

SPECIAL REPORT

DARPA: Gambling on high-risk R&D

INTERNATIONAL JOURNAL OF RESEARCH, DEVELOPMENT, AND QUALITY ASSURANCE

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ON THE COVER
George Hatsopoulos (front row, red tie), CEO of Thermo Electron Corp., *R&D* magazine's first Corporation of the Year, is shown with company employees. That's a 150-ton gas-engine-driven cogenerating air conditioner, one of the company's products. *Photo by Christopher Morrow.*

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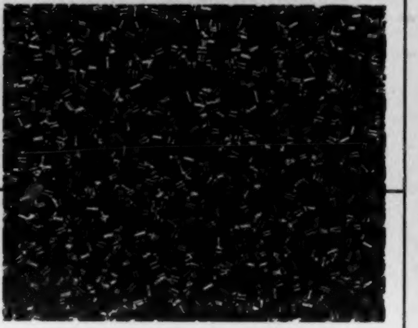

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R&D BUSINESS

Biotech firms need more money for R&D

RESEARCH-BASED companies continue to deploy resources to biotechnology, but money is not available to do everything," says Irwin M. Lerner, president and CEO of Hoffman-La Roche, a multinational pharmaceutical company.

Lerner's comments are part of a biotech industrial survey that cites limited R&D funding, expensive capital, and complex regulations as the most crucial issues facing U.S. biotech companies.

Across all emerging technologies, seed capital in privately held companies is down 30% to 50% from two years ago. Second- and third-round financing is even harder to obtain.

For companies that overcome the financial hurdles, future prospects are bright. Over the next five years, the U.S. biotechnology industry expects a 1,000% increase in sales, a tripling of marketing and manufacturing personnel, and a 50% increase in R&D personnel, according to the survey.

Most biotech companies are currently negotiating strategic alliances with firms in foreign markets. An even larger proportion are negotiating alliances for the U.S. market.

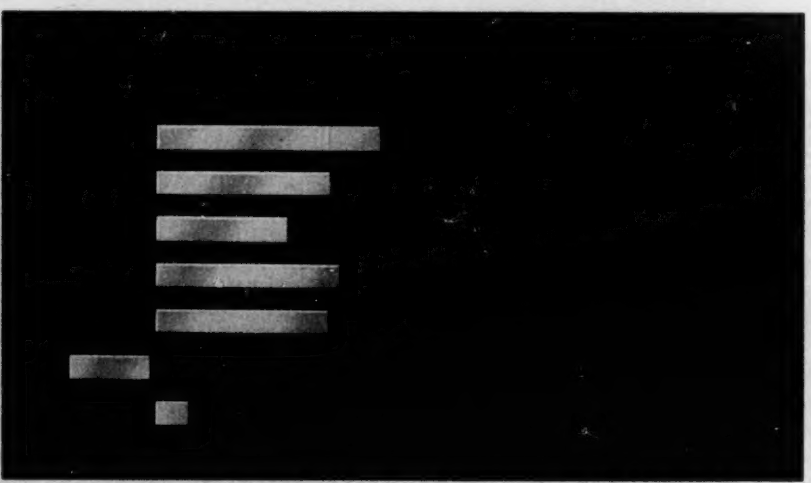
The short-term development bias in the U.S. may force some biotech companies to join U.S. pharmaceutical firms or Japanese companies with the backing to support short-term realities and long-term plans.

"The U.S. will be partners and competitors with Japan in biotechnology," says Lerner. "Japan has reached the point where licensing is no longer their best strategic option."

Japan is expected to be a major player in biotechnology in the 1990s. The Japanese government is actively supporting its Human Frontier basic science project with a budget of $17 billion.

"The U.S. remains the world leader in biotechnology and can continue [to be the leader] provided the climate remains supportive," says Lerner.

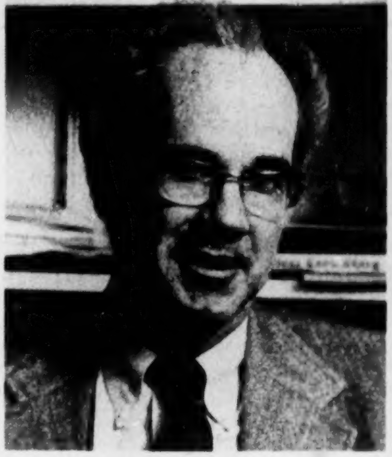
The survey, "Biotech 90: Into the Next Decade," was conducted by Ernst & Young, 1 Sansome St., Suite 3500, San Francisco, CA 94104. Cost: $80. —*Tim Studt*



***Most biotech indicators** increased from last year; but asset growth was outpaced because not enough financing was available to keep pace with the sector's growth.*

Harvard's Walton: U.S. technology underused

THE U.S. is not using technology effectively, Japan is," says Harvard Business School's Richard Walton in his recently published book on information technologies (IT).



***Richard Walton:** New technology must include organizational changes.*

Walton, the Jesse Isidor Straus professor of business administration, cites a Harvard study that compares 95 flexible manufacturing systems in Japan and the U.S. This study reveals that the average number of parts produced on U.S. systems is 10, while the number on Japanese systems is 93.

These differences are attributed to the degree of computer control in the system, the technical skill of the work force, and management approaches.

Walton details the experiences of 19 organizations that "struggled" to integrate new information systems into their companies.

"Advanced technology by itself is unable to guarantee the advantages regularly delivered by technology accompanied by work reorganization," says Walton.

Up and Running: Integrating Information Technology and the Organization is available from Harvard Business School Press, Soldiers Field, Boston, MA. 617/495-6700. ☐

Get your patents on the fast track

A PROCEDURE that can reduce the time required to process a new patent application is available but not widely known, according to Stephen Glazier, a New York-based patent attorney.

"Within the patent office, there's a

fast track and a slow track, and unless you request otherwise, you get put on the slow track," says Glazier.

To get on the fast track, an inventor must petition for and be granted an accelerated examination. This process moves the application to the front of the line, but limits the interaction between the applicant and the examiner to one amendment cycle.

The accelerated process can work well when the application is for a simple device or process and not complicated by closely related technologies.

A petition for an accelerated examination must be customized for each application and include the results and analysis of a patent search.

Although legal costs for this process can be higher, getting a patent faster can be important in obtaining venture capital and bringing a product to market. "If you have a person with a checkbook waiting to give you money, it's worth a few thousand dollars to get rid of a two-year wait," Glazier says.

While inventors can apply for acceleration with any patent application, the patent law favors accelerating inventions relating to environmental quality, energy conservation, safe research of DNA, and superconductivity. An inventor's poor health or advanced age, manufacture contingent upon a patent, and infringement also can accelerate a patent application.

"It's not a procedure for all applications," Glazier says. "You have to sit down with your patent attorney and look at the individual case."

—*Elizabeth Dougherty*

Top 10 Japanese spenders on R&D

		1988 spending*
1	Fujitsu	$1,690
2	NEC	1,450
3	Hitachi	1,430
4	Toshiba	980
5	Nippon Teleg./Tel.	850
6	Mitsubishi Elec.	600
7	Canon	530
8	Tokyo Elec. Power	420
9	Fuji Photo Film	380
10	Mitsubishi Motor	330

*Millions of U.S. dollars

High tech leads R&D spending in Japan

HIGHLY DIVERSIFIED electronics firms head the list of Japan's biggest R&D spenders, says Nihon Keizai Shimbun, a Tokyo-based publishing firm.

The top spender, Fujitsu, spends most of its $1.7 billion R&D budget on computer and semiconductor research. For computer research, the focus is on supercomputers, artificial intelligence, and machine translation. Semiconductor research concentrates on 4- and 16-Mbit DRAM devices.

The R&D costs are defined as those allocated to sales management expenses in the profit and loss account and do not include those apportioned to production costs. If those production R&D costs are included, Hitachi's R&D spending is more than $2.3 billion. ☐

Do you live in an R&D hotbed?

NEW YORK, MICHIGAN, and California were the top three states for the construction of new R&D centers in 1988, according to the Industrial Development Research Council, an Atlanta-based association of real estate executives.

The top five cities with new R&D centers last year were Ann Arbor (9), Detroit (8), Raleigh-Durham (7), and Atlanta, San Francisco/Oakland, and Syracuse (6 each). There were 266 new R&D facilities started in 1988, an 8% increase, bringing the U.S. total to 3,570. Washington, DC (190), Boston (148), and Detroit (95) continued their leadership in the number of centers. The listing includes all new and existing corporate, government, university, and nonprofit facilities.

State	New centers in 1988	Total R&D centers
California	22	315
Massachusetts	1	194
Michigan	28	191
Pennsylvania	16	188
New York	29	139
Maryland	1	134
Florida	15	124
Texas	9	109
Illinois	4	106
Ohio	7	98

Big Blue's big bang will be coming soon

MORE THAN two thirds of IBM's R&D expenditures over the past six years, or $13 billion, has yet to be associated with any notable products, according to International Technology Group (ITG), a Los Altos, CA, consulting firm.

ITG predicts that this money has been spent to develop a whole new line of mainframes, midrange computer systems, workstations, and communication systems that IBM plans to introduce in 1991 or 1992. This "big bang" will culminate a long-term research plan that will reinforce IBM's position for those customers with large computer systems.

"IBM has made some short-term mistakes. They also have lost market share to companies like Amdahl due to their long-term planning," says Brian Jeffrey, managing director of ITG.

By the early 1990s, however, he predicts IBM will pull ahead in computer architecture, data communications, and basic components and materials.

Part of IBM's strategy, ITG contends, is that most current IBM equipment will be compatible with the new equipment and will be upgradable with simple board exchanges.

Mainframe replacements

At the top of the line, IBM's current 32-bit mainframe (Model 3090) will be replaced by a 48-bit hybrid system, called Summit, that implements a preliminary form of parallel processing. The new mainframe will use limited instruction set computing (LISC) hardware and reduced instruction set computing (RISC) input-output process architecture.

Summit also will have supercomputer capabilities. IBM and Steve Chen, formerly of Cray Research, have been working on a parallel processing system that also is expected to be introduced in the 1991 time frame. ITG expects this system to be a functional process module that can be added to the Summit mainframe. Its performance is expected to be between that of a minisuper and a Cray-type supercomputer, but it will still have the multifunctional capabilities typical of a mainframe.

ITG also predicts a second round of new IBM product introductions to occur about 1996. Until then, IBM has been acquiring software companies as a holding action and to increase acceptance of its current products. ☐

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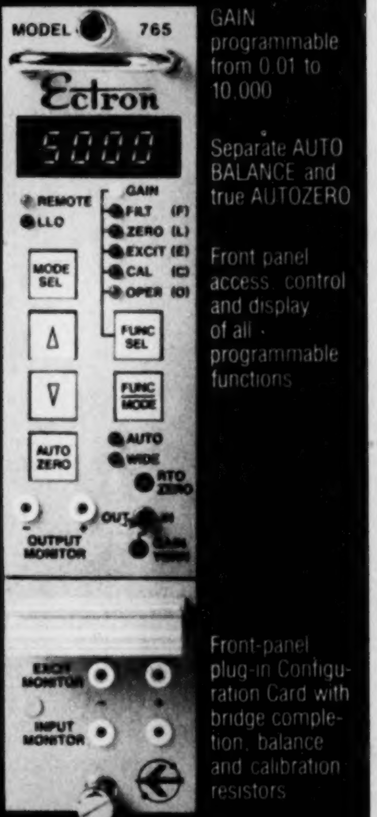

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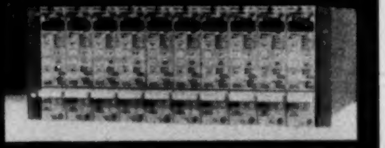

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Brian McIntyre and Rachelle Perman, Univ. of Rochester, and Barri Gold, GW Instruments

Combining a Macintosh PC and an SEM with graphics software creates a high-resolution laboratory lithography system that can perform many important microfabrication functions, without the high cost of electron-beam equipment.

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Sean Brennan and Arthur Bienenstock, Stanford Synchrotron Radiation Laboratory

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65 New Controller Extends The Range of BA Ion Gages

Ron Paitich, Terranova Scientific Inc.

A Bayard-Alpert gage with a wide-range controller can measure pressures throughout a semiconductor or optical process. By improving the processing of a BA gage's output signals, its use can extend the gage's upper pressure limit from 10^{-3} to 1 torr.

ON THE COVER

A high-resolution laboratory lithography system might be on your wish list. This one, shown with developer Brian McIntyre of the Univ. of Rochester's Institute of Optics, NY, costs less than $90,000. *Photo by Andrew Davidhazy.*

READER SURVEY

The editors of *R&D* magazine would like to know more about you. Tell us what you like and don't like about your profession by filling out the Career Satisfaction Survey on page 27. Look for the results in an upcoming issue.

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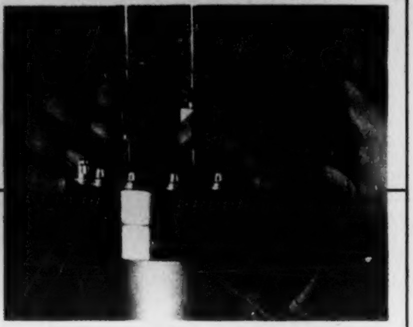

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R&D BUSINESS

Flat equipment growth forecast for next year

AFTER MORE THAN 20% growth in U.S. equipment purchases in the past three years, only a 1.5% increase is forecast for 1990, according to Kermit Baker, director of economics at Cahners Economics.

"The past growth took care of a surge in exports which now seems to be dying out," says Baker.

For 1991, Cahners forecasts a 3.4% increase in equipment purchases. This follows a general cyclical expansion that Cahners forecasts to begin in mid-1990.

The 1991 equipment increase will be split between trade and domestic demands. "However, most of it will be due to domestic demand; the big improvements in trade are behind us," says Baker. ☐

Mainframe computers take center stage

THE MAINFRAME technical-computing stage has new players in it after recent announcements by U.S. computer makers. Two mainframe heavies, IBM and Control Data, announced model changes and two previously non-mainframe suppliers, Tandem and Digital Equipment, entered the market.

Short-term effects on technical computing are negligible. However, long-term dominance by IBM in this $21 billion (technical computing) market appears to have been shaken.

Tandem, Digital, and Control Data all announced products that outperform IBM's 3090 system, are equal to or less costly than the 3090, and are air-cooled (the 3090 is water-cooled).

Tandem's fault-tolerant Cyclone mainframe, while capable of handling numerical processing, initially will not be targeted at scientific customers, according to a Tandem analyst. Tandem has already shown that it can at least match IBM in the larger transaction-type market at less than half the cost.

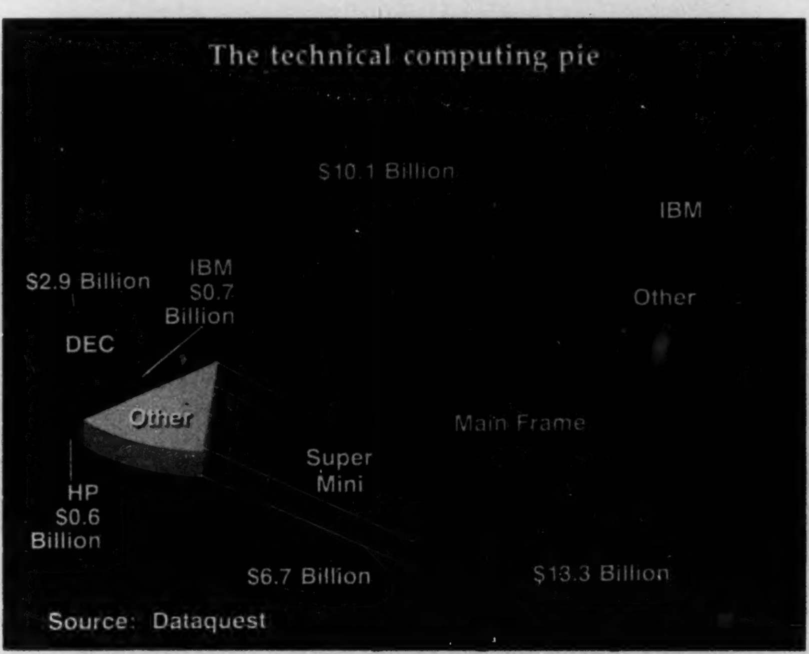
Digital's VAX 9000 will provide more competition for IBM. However, "the 9000 will be an add-on system that will provide existing VAX users with a strong upgrade path," says Doug Crook, an analyst at Dataquest, a Santa Clara, CA, market research firm.

Initially, the 9000 won't displace IBM. "Digital was forced into mainframes because its margins in lower-level computers were being eaten into by competitors," says Crook.

Control Data's Cyber 2000 should compete more directly with IBM. The 2000 is targeted at scientists and engineers with a 30-MFLOPS numerical processing capability. Cray-2 supercomputers are rated at 38 MFLOPS.

To counter these threats, IBM lowered some 3090 prices—replacements are not expected until 1991.

Users' desire to be software compatible with their existing IBM equipment will keep IBM in the forefront for the near-term. But, when new products start appearing next year, IBM will be in a competitive situation it has not previously been in. —*Tim Studt*



***IBM's current large** share of the mainframe market will retain its dominance in technical computing despite recent announcements of competitive products.*

Form alliances now or forfeit future: Baranson

***IITRI's Jack Baranson:** Alliances with competitors can shorten R&D times.*

COMPANIES that fail to form strategic business alliances with other firms imperil their future prospects," says Jack Baranson, associate director at the Chicago-based Manufacturing Productivity Center of IIT Research Institute.

The rapid pace of technology is telescoping the time cycle so that even large companies with substantial re-

R&D

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Dick Johnson leads research to make aging airplanes safer at Boeing's Everett, WA, facility. *Photo by Tim Davis.*

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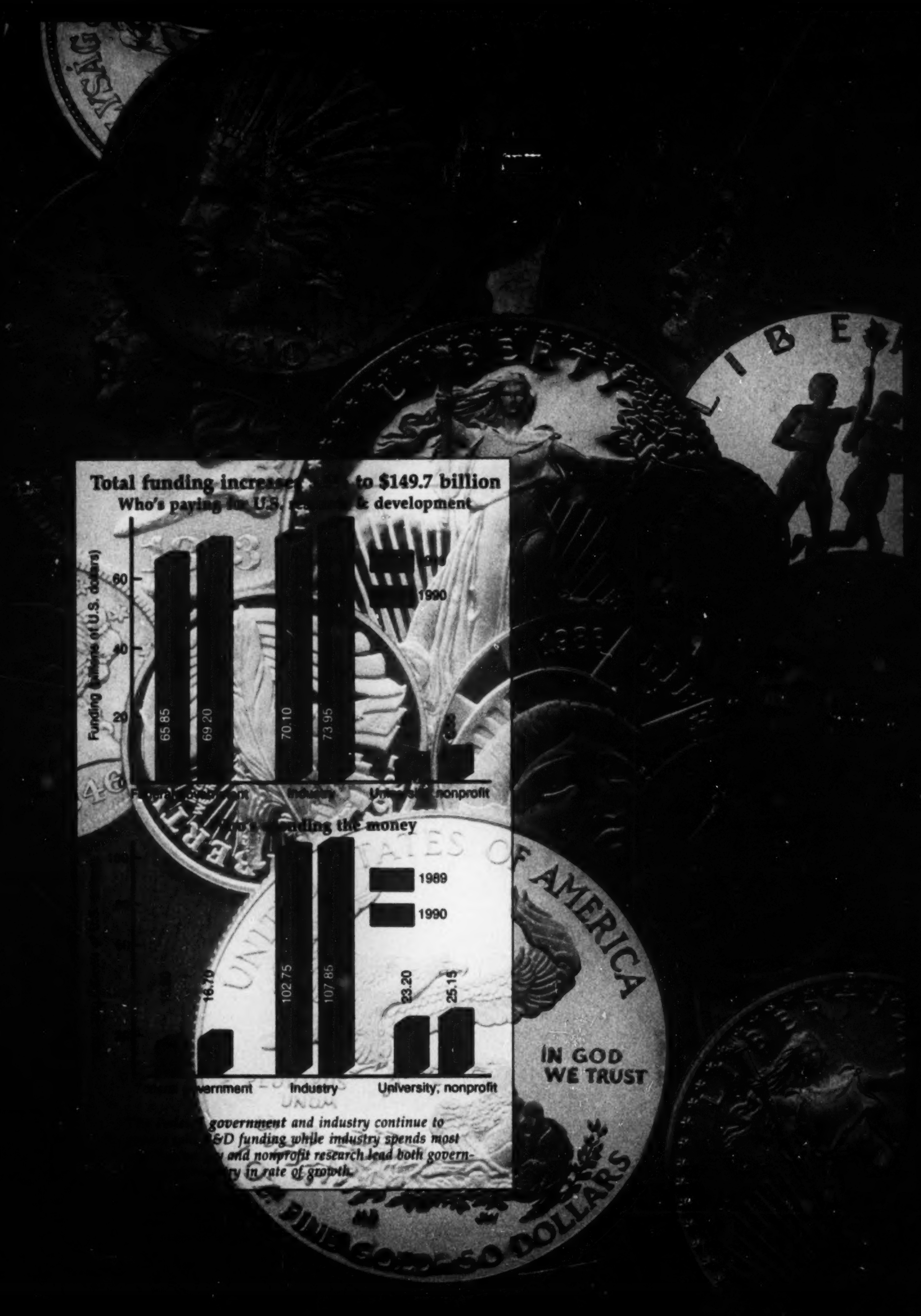


government and industry continue to &D funding while industry spends most y and nonprofit research lead both government ry in rate of growth.

There's No Joy in This Year's $150 Billion for R&D

Don't let the big numbers fool you—there won't be a lot of new dollars for research this year.

*By **Tim Studt**, Associate Editor,* R&D *magazine*

A FEDERAL BUDGET deficit that won't go away, money costs that are twice what our international competitors pay, and continued short-term thinking by corporate America are among the harsh economic realities that R&D budget managers face in 1990.

Add to this the political effects of a thawing cold war, a precipitous drop in defense spending, and renewed saber-rattling with Japan and Europe over trade issues, and you have a global picture filled with uncertainty.

The net result of these factors is *R&D* magazine's forecast that government, industry, universities, and other nonprofit research centers will spend $149.7 billion on R&D in the U.S. this year.

If that sounds like a lot of money, it's not. Our $130.8-billion forecast for 1989 has been adjusted to account for the changing R&D environment in the past 10 years (see box).

As the accompanying charts show, the 1990 forecast breaks down as follows: The Federal government will spend $69.2 billion, up 5.1% from last year's revised figure. Industry will devote $73.95 billion, a 5.5% increase from a year ago. Universities and nonprofit centers will fork up $6.55 billion, a whopping 12.9% increase over 1989's figure.

As in the past, industry will actually carry out the bulk of the research, $107.85 billion or 72% of the total. Federal labs will perform $16.7 billion (11.2%), and universities and nonprofit centers—again showing growth—will do $25.15 billion (16.8%).

A declining, but still large, defense budget, entitlement program growth, and the budget deficit restrict any real Federal R&D growth.

In recent weeks, the Bush Administration's support for many popular R&D programs has been faltering. Such high-visibility programs as Sematech, DARPA (especially its HDTV project), the Dept. of Commerce's Technology Assessment Program, and the Pentagon's Manufacturing Technology Program are among those coming under close White House scrutiny for possible cutbacks.

R&D

Increases in U.S. R&D continue to trail those of Japan and Europe.

The area most severely affected by budget constraints has been defense R&D, especially aerospace research. Of the $61.9 billion in Federal R&D obligations for 1989, the defense share was $37.6 billion or 60.8%.

Declining defense share

Although the absolute value of defense spending increased 6.2% from 1988 values (due to procurement items), its share of total government research obligations dropped almost 2%, with even larger drops projected for the next several years.

With world political events making military readiness almost secondary to industrial competitiveness, defense R&D development will continue to shrink.

"In the long term, I think that the [defense] research institutions are going to get hit hard," says Kenneth Smith, vice president for research at Massachusetts Institute of Technology (MIT), Cambridge. With most defense programs surviving the FY1990 budget process, he predicts that FY1991 will be the year for "big hits."

"With the developments in Europe, you're not going to sustain a $300-billion military budget," says Kosta Tsipis, director of MIT's Program in Science & Technology for International Security. "And since the ratio of R&D to procurement is fixed at 47%, you're going to see R&D go down."

The defense slowdown already has depressed the value of aerospace industries. Most aerospace companies are being forced to accept smaller operating margins and many others are taking charges against their backlog of fixed-price R&D contracts.

The Gramm-Rudman budget-deficit law, which mandates a FY1990 $100-billion deficit ceiling, adds another layer of woe to defense research. A FY1990 sequester was ordered into place in October 1989 by President Bush, half of which by law must be absorbed by the Dept. of Defense. Analysts are predicting that Gramm-Rudman pressures will force 2% annual real declines in defense budgets for FY1991 through FY1994.

The DOD comptroller already has requested that the armed services make $180 billion in budget cuts over the next four years.

Most nondefense research agencies had substantial funding increases last year. The 1989 R&D obligations, according to NSF sources, were:

- National Institutes of Health: $6.8 billion, up 8.0% from 1988

Most defense R&D programs survived FY1990 budgets, but FY1991 will be the year for 'big hits.'

- NASA: $5.7 billion, up 31.4%
- Dept. of Energy: $5.5 billion, up 8.8%
- National Science Foundation: $1.7 billion, up 8.6%
- Dept. of Agriculture: $1.0 billion, no change
- Dept. of Commerce: $405 million, up 4.3%
- Dept. of Transportation: $335 million, up 10.2%.

An industrial balancing act

The static situation in industrial R&D funding reflects a balancing of short-term "survival" and long-term growth efforts by companies. Many companies use survival funding to support formerly neglected manufacturing operations. The profits from these existing product lines help pay for long-term developments.

DuPont spends 55% of its $1.4-billion R&D budget on short-term projects and the remainder on projects with 5- to 10-year lives. As their long-term projects succeed, the Wilmington, DE, chemical giant needs even more research. "The balance is not only how much can you afford today, but the implications of what you spend today as far as demanding even more spending in the future," says Alexander MacLachlan, senior vice president of technology.

DuPont and other companies also are trying to get more out of their R&D money.

"Companies are much more interested in leveraging their R&D dollars," says MacLachlan. "Industry, and not just U.S. industry, is working more closely with universities to do early technological development that otherwise might have been done internally, but because of cost, perhaps can be done more expeditiously or more cheaply in universities.

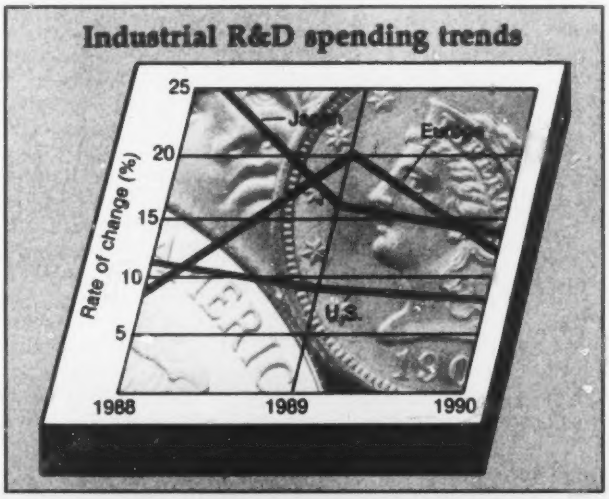
"We're also starting to involve ourselves with government labs because they are a rich source of technology," MacLachlan continues. "But this is a complicated area and slowed by a lot of suspicion [of the bureaucracy]."

Most industrial managers are confident of their companies' success. "The funding I have is commensurate with the opportunities that I'm working with," says Carl Scaccia, director of R&D at Ashland Chemical, Columbus, OH. "If better and higher levels of opportunity were to be presented, we would get additional funding."

Investment inequities

Foreign competitors invest more, save more, and pay less for investments.

Our funding forecast reveals a continuation of proportionately lower U.S. R&D spending than that of our major industrial competitors, Japan


Industrial R&D spending trends

In 1990, both Japanese and European companies will increase their R&D more than 12%, while U.S. company increases will be less than 8%. Forecast is made from Securities and Exchange Commission data and is courtesy of Schonfeld & Associates, Evanston, IL.

Changing the sampling procedure

R&D MAGAZINES'S 1990 funding forecast shows a 5.6% increase over our revised 1989 figures. Although this increase improves upon 1989's 4.6% increase, it indicates a real funding growth of less than 1% when adjusted for inflation (based on the Cahners Economics Production Price Index of 4.9%, which is more appropriate for research costs than the Consumer Price Index). Using constant 1982 dollars, the increase is 1.3%.

This year's figures have been adjusted upward from the actual numbers used in the 1989 forecast. This adjustment reflects a new sampling procedure by the National Science Foundation that includes industries inadequately sampled in the past.

Previous funding forecasts used a sampling procedure established in 1981. Each year the largest R&D performers were surveyed, and total funding was obtained by imputing a difference for the remaining amount.

A sampling change was required when actual 1986 expenditures compared to the 1981-based survey revealed the survey to be about $7 billion low. Using a new 1987 survey indicated that more than half of this difference came from increased R&D by nonmanufacturing companies that had not been sampled.

Using the 1987 sampling procedure, the original 1989 funding was adjusted from $130.8 billion to $141.75 billion. Of this $10.95-billion difference, $8.95 billion came from industry, mostly software development and engineering services companies.

These companies have had dramatic increases in their R&D during the past 10 years. Most software companies and manufacturing research centers didn't even exist in 1981.

Additional industrial increases came from R&D in communication service companies, independent research laboratories, utilities, and small companies. The 1981-based survey was heavily biased in favor of large companies.

The remaining adjustment in 1989 funding went to government research ($1 billion), which was not as hard hit by last year's general budget cutback as originally forecast, and university performance ($1 billion).

The U.S. must face the realities of a global economy, if it is going to have any future.

and Europe (see chart). The Japanese especially are investing in their companies at an astounding rate:

- The ratio of capital investment to gross national product (GNP) in Japan will climb to nearly 25% in 1990, up two percentage points from 1989. In the U.S., this ratio will reach 9%, a one percentage point decrease from last year.
- Most Japanese technology companies will up their annual R&D budget by 14%, compared with increases by U.S. companies of 9%.
- This year's ratio of nondefense R&D to GNP is projected at 2.8% in Japan and 2.0% in the U.S.

Some of this investment will satisfy growing internal demand; however, Japan's long-term technological growth still is outpacing U.S. growth.

One reason the Japanese can invest more is that their real after-tax cost of funds is only 2.5% (for 1989). In the U.S., the cost of funds is 5%.

Personal savings rates affect the cost of money. Japan's household savings rate, as a percent of disposable income, is 20%—in the U.S., it's 6%

A lower savings rate imperils America's future development capabilities according to physicist George Hatsopoulos, CEO of Thermo Electron Corp., Waltham, MA, and chairman of the Federal Reserve Bank of Boston.

"Foreign investment in U.S. land, corporations, and securities [which finances our growth] induced by a low dollar cannot continue indefinitely," says Hatsopoulos. "Ultimately, inadequate national saving must translate into reduced investment."

A global viewpoint

U.S. companies are finding ways to beat foreign competition.

In one situation, companies are concentrating on a small number of long-term, high-tech ventures. Dow Chemical, for example, is spending a major portion of its more than $2.5-billion R&D budget on such ventures as engineering thermoplastics and pharmaceuticals. They are prepared to absorb losses for five years or longer to develop new products.

In another situation, two or more companies are combining their R&D capabilities. Dow bought a majority stake in Marion Labs, Kansas City, MO, so it could get into pharmaceuticals quickly. Ford, GM, and Chrysler formed a cooperative research group to investigate structural composites. Squibb formed a technology-sharing alliance with Denmark's Novo to produce a new insulin product.

"The days of doing it all yourself are gone," says John McTague, vice president for research, Ford Motor Co., Dearborn, MI. "The key [to forming a joint venture] is to find things that are mutually beneficial."

Some industries are keeping pace with foreign competitors. "In motor vehicles, the U.S. and Japan are dead on at 3% of sales [for research]," says McTague.

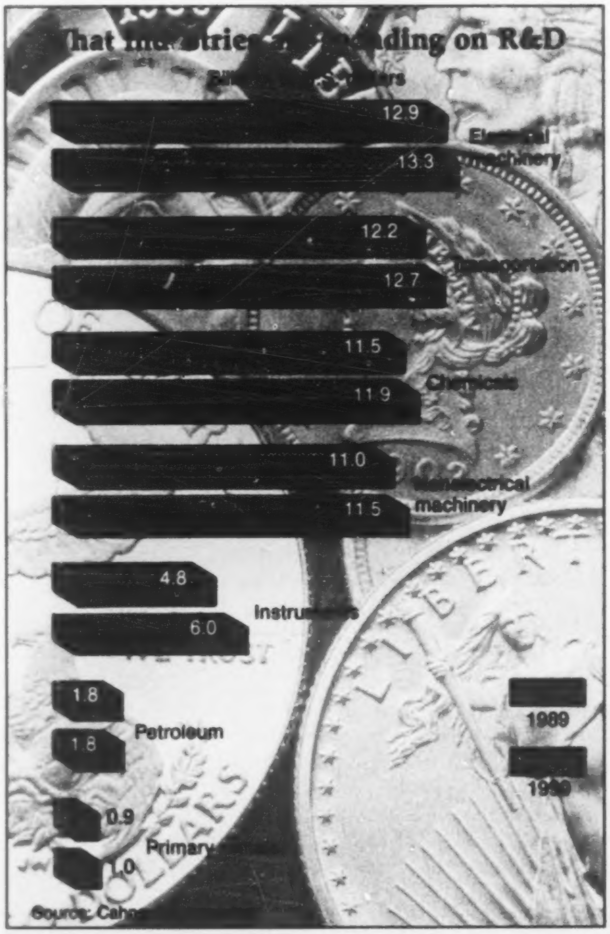
In aerospace, Seattle's Boeing has formed technical alliances with Japanese heavy industrial manufacturers. But the handwriting is on the wall—the Japanese have made aerospace their next market objective.

The U.S. aerospace industry has been its leading exporter for the past four years, yet "the aerospace products on which this trade surplus is based draw on technologies developed 10 to 25 years ago," says Edward Hennessey, Jr., chairman of Allied-Signal, Morristown, NJ.

The industry position has remained strong despite reductions in government-funded support of aeronautical R&D, but long-term technological leadership has weakened.

"U.S. aerospace, like all industries, must face up to the realities of a global economy if it's going to have any future," says Hennessey. **R&D**

Despite an expanding economy for the eighth consecutive year, industrial R&D increases in 1990 won't match inflation levels in most sectors. The exception: instrument industries, whose growth continues to beat inflation.



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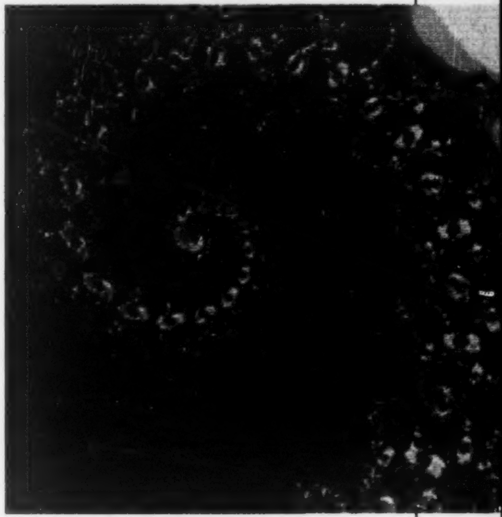

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This laser-based indirect thermal lens spectroscopy detection system, shown with developer Donald Bobbitt from Univ. of Arkansas, reveals transparent molecules without using dyes or derivatives. Article on page 94. *Photo by Wendy Robertson.*

READER SURVEY

Please tell us what you like and don't like about your profession by filling out the Career Satisfaction Survey on page 173. Look for the results in an upcoming issue.

Electrical and Electronic Instrument Markets Strong

Latest *R&D Magazine* Trendsurvey of use and intention to buy shows steady demand for 31 types of research tools.

By Robert R. Jones, Executive Editor, R&D *Magazine*

THE MARKET for electrical and electronic instruments remains strong. There is good reason to believe that more than half of the workers in research, development, and quality assurance plan to purchase one or more instruments within the next 12 months.

In addition, it is a market that has not changed greatly during the 80s. This conclusion comes from a recent Trendsurvey of 291 *R&D Magazine* readers.

When those readers were asked whether they planned to purchase one or more of a list of electrical or electronic instruments within the next 12 months, 55.7% replied that they did.

Instruments now used

As to the types of instruments they now use, the 10 types listed most frequently, in descending order, were printer-plotters, digital multimeters, digital voltmeters, dc power supplies, analog oscilloscopes, time and frequency counters, standards calibration instruments, frequency generators, digital electronic thermometers, and multichannel oscilloscopes.

In the three preceding Trendsurveys of electrical and electronic instrument use, published in *R&D Magazine* issues of April 1988, November 1984, and November 1983, printer-plotters also held the top position in terms of most-frequently-listed instrument types.

Of the 10 instrument types most-often listed in the current survey as used by workers in research, development, and quality assurance, six appeared in the top 10 of all four studies: printer-plotters, digital voltmeters, dc power supplies, time and frequency counters, frequency generators, and digital electronic thermometers.

Two of this year's top 10, multichannel oscilloscopes and digital multimeters, were in three of the four top 10s.

The remaining two in this year's top 10, analog oscilloscopes and standards calibrations instruments, were new in the survey questions this year, replacing microprocessors and general purpose oscilloscopes which had appeared in the top 10 of the three previous studies.

It was felt that these products, microprocessors and general-purpose oscilloscopes, are so widely used and generally accepted that their markets were well established and clearly defined. Further analysis of the markets for these two did not appear to be needed at this time.

Instruments to acquire

When readers were asked what types of instruments they plan to acquire within the next 12 months, the 10 most-frequently listed were, in descending order, digital storage oscilloscopes, printer-plotters, analog-to-digital converters, line conditioners with uninterruptible power supplies, dc power supplies, digital voltmeters, microprocessor development systems, standards calibration instruments, digital multimeters, and IEEE-488 buses.

Of the 10, five have been on the most-wanted list of *R&D Magazine* readers in the three preceding studies and also in this one: printer-plotters, line conditioners with uninterruptible power supplies, dc power supplies, digital multimeters, and IEEE-488 buses.

Two others of this year's top 10, digital voltmeters and microprocessor development systems, have been in the top 10 in three of the past four studies.

Two of the top 10, analog to digital converters and standards calibration instruments are new to the study this year.

As was mentioned, digital storage oscilloscopes (DSO) head the list of the 10 most-wanted instrument types this year. This is the first year for DSOs to appear in the top 10, but perhaps its appearance there should not come as a total surprise.

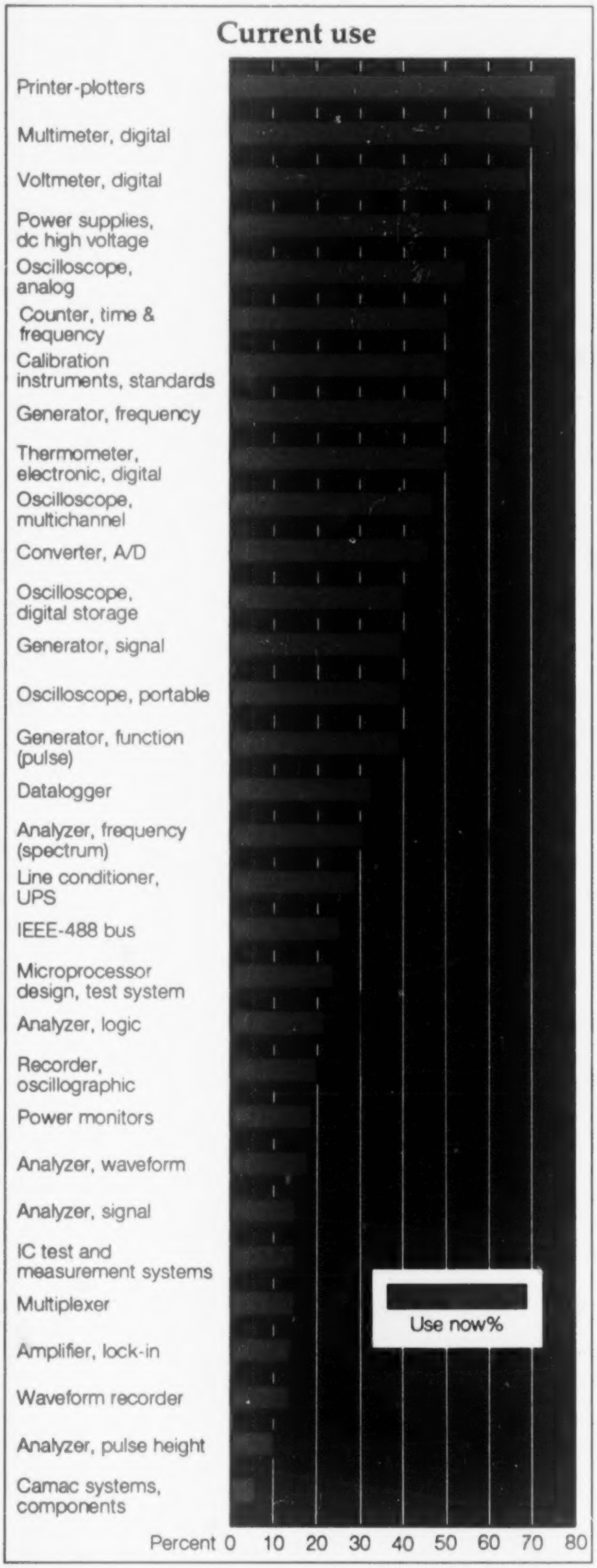
The DSO growth rate (this term is defined below) has risen from an eleventh ranking in 1984 to fifth in 1988 and is third-high now.

Growth rate

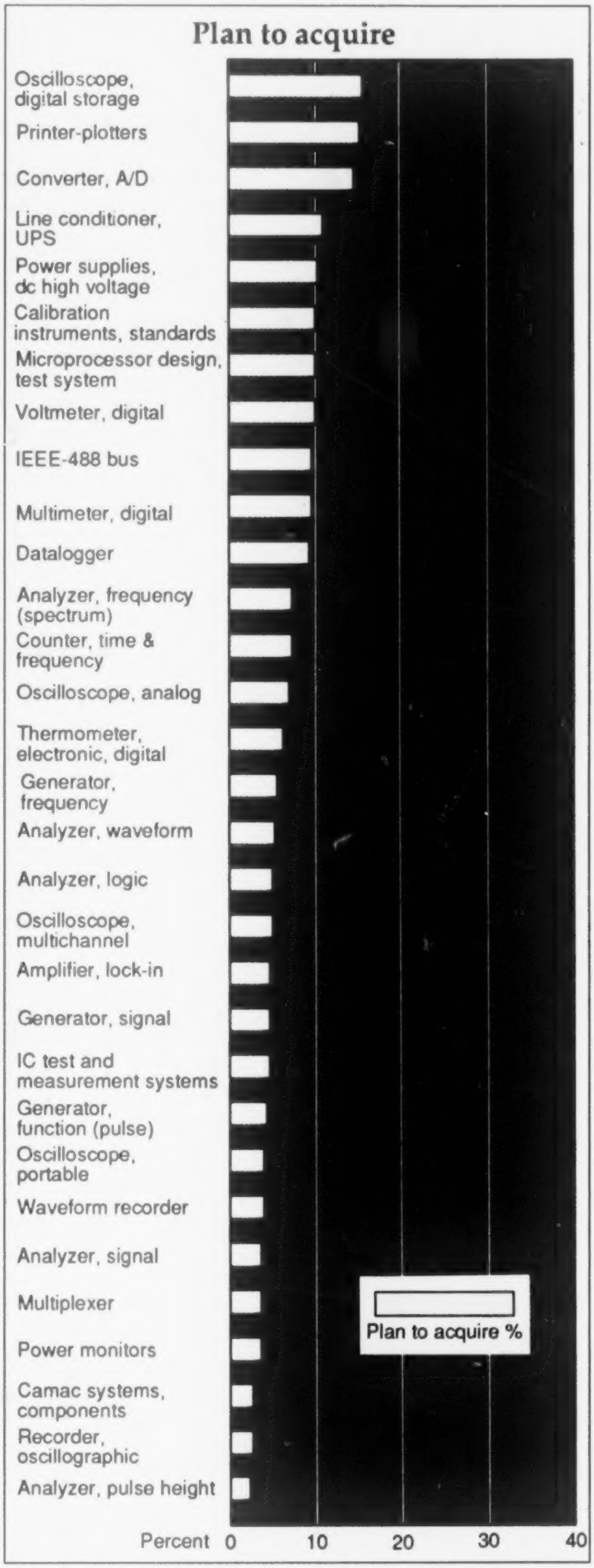
With the Trendsurvey's *use now* and *plan to acquire* data, it is possible to establish a growth rate for the use of each instrument type.

This gives an insight into the data that is not revealed otherwise. For example, multichannel oscilloscopes rank tenth in the list of most-used instrument types at 47.8%. However, they score only 5.2% in plan to acquire, far below the IEEE-488 bus which, at 9.6%, is the lowest-ranked instrument in the top 10 of plan to acquire,

To derive the growth rate of each instrument type, the number of re-



Current use



Plan to acquire

The growth rate in many instrument categories indicates that new users are entering the market.

spondents planning to acquire is divided by the number now using. This gives a rough guide to market potential by instrument type.

Thus the growth rate for the multichannel oscilloscope is 10.9% while that for the IEEE-488 bus is 36.8%.

Consistent data

This occasional study of the use of electrical and electronic instruments has been conducted by this magazine over a number of years, and the consistency of results from one study to the next gives a strong indication of the survey's validity.

For example, the percentages of responses as categorized by workplace shows this consistency:

	1983	1984	1988	1990
Industry	52.6	53.6	55.9	59.5
University	19.6	21.3	18.4	19.7
Non-profit Institution	7.4	6.1	3.0	2.4
Medical Research	2.6	3.3	2.1	1.4
Gov't	—	—	13.6	10.7
Other*	14.9	14.0	3.8	6.2

*Includes *Gov't* in '83, '84

Likewise, the percentages of geographical distribution once again mirror this magazine's total circulation by regions: Northeast 7.2, Middle Atlantic 17.2, E. North Central 19.6, W. North Central 7.2, S. Atlantic 10.3, E. South Central 4.8, W. South Central 6.5, Mountain 9.8, and Pacific 13.4.

Survey method

This Trendsurvey was conducted by including a prepaid card in a late September 1989 postcard mailing to *R&D Magazine* subscribers. Readers were asked specifically about the 31 instruments which are listed in this report.

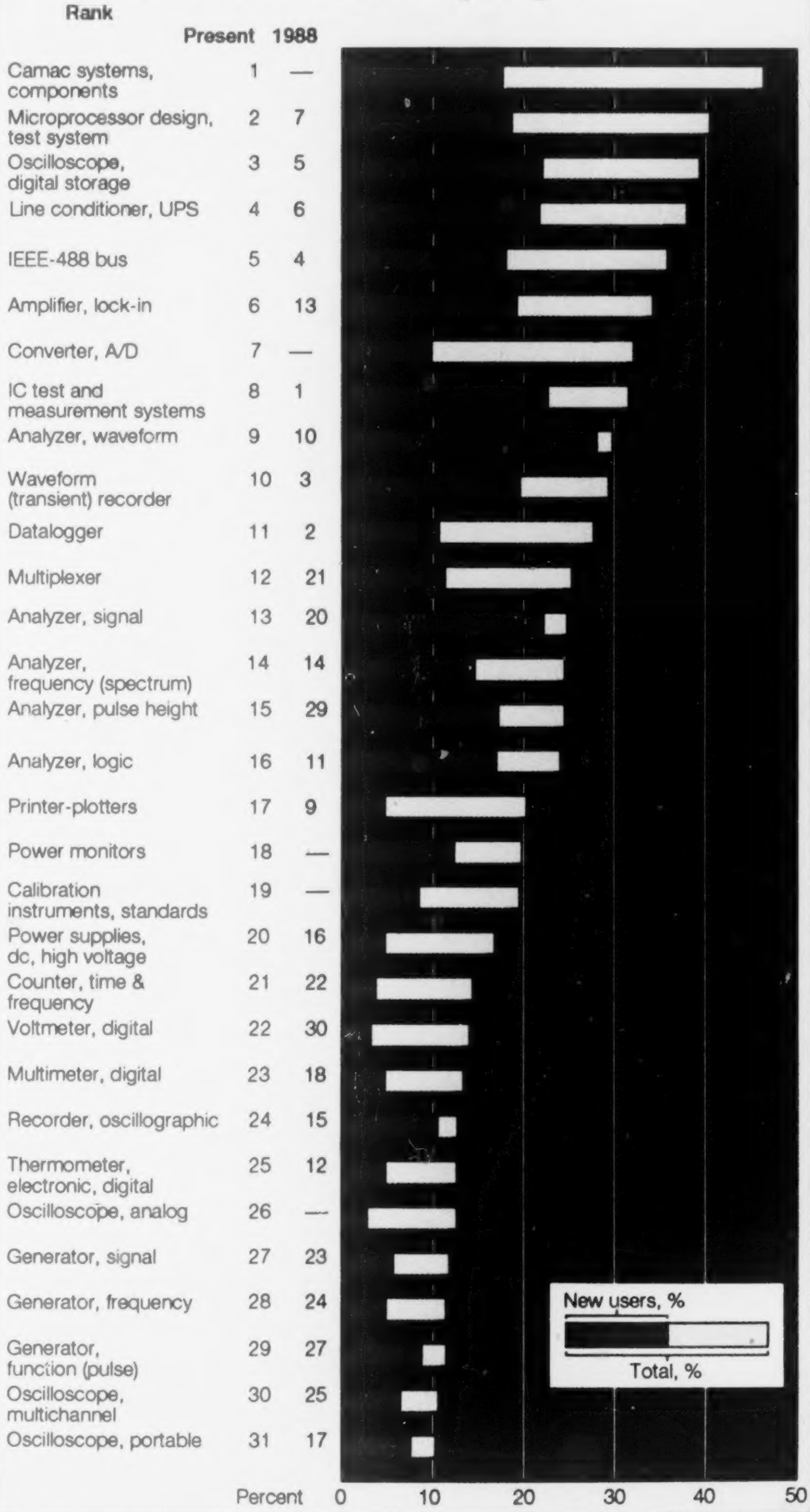
Most of the replies were received in the month following the October 13 stock market decline and, if anything, instrument purchase intentions may have been negatively biased by that event. **R&D**

READER RESPONSE PANEL

Please rate your interest in this article by circling the appropriate number on the Reader Service Card.

High **395** Medium **397** Low **399**

Growth rate: Plan to acquire/present use



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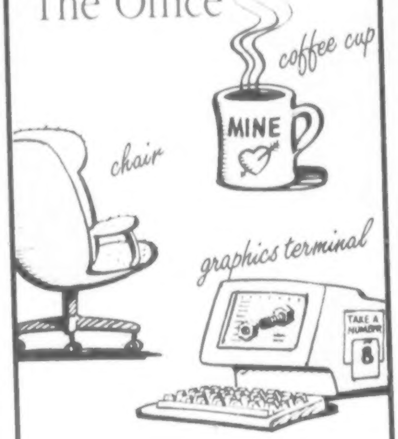
Three Things
You Shouldn't
Have To Share At
The Office



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Special Computer Section

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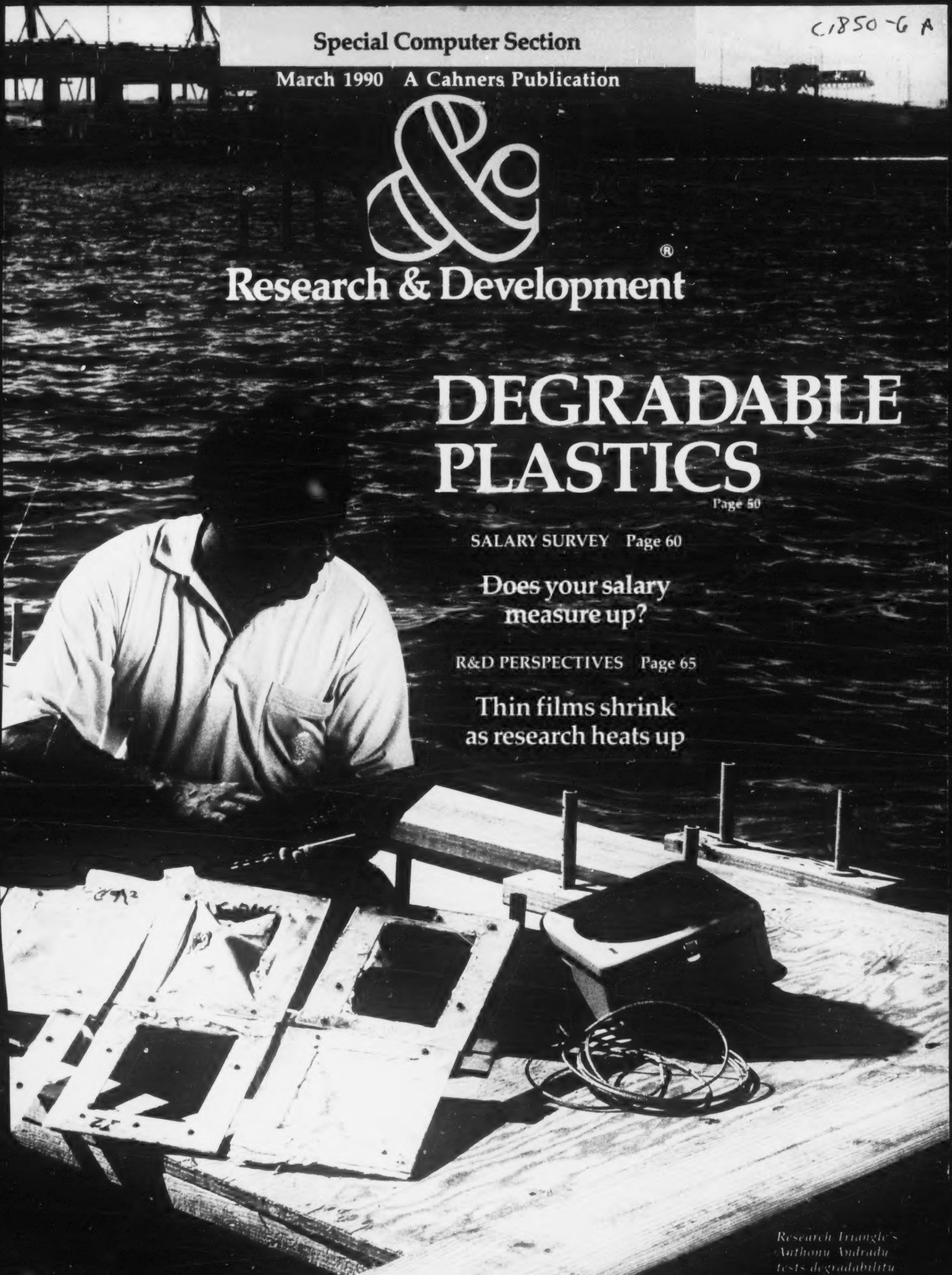

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Does your salary measure up?

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Thin films shrink as research heats up

Research Triangle's Anthony Andrady tests degradability of plastics in water

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On a dock at his Miami test site, researcher Anthony Andrady from Research Triangle Institute, Research Triangle Park, NC, tests the degradability of plastic samples immersed in seawater. Because little information exists about what is and is not degradable, research like Andrady's focuses on evaluating existing materials under variable conditions, such as in water vs. in soil.

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Tim Studt, Associate Editor, R&D Magazine

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Robert R. Jones, Executive Editor, R&D Magazine

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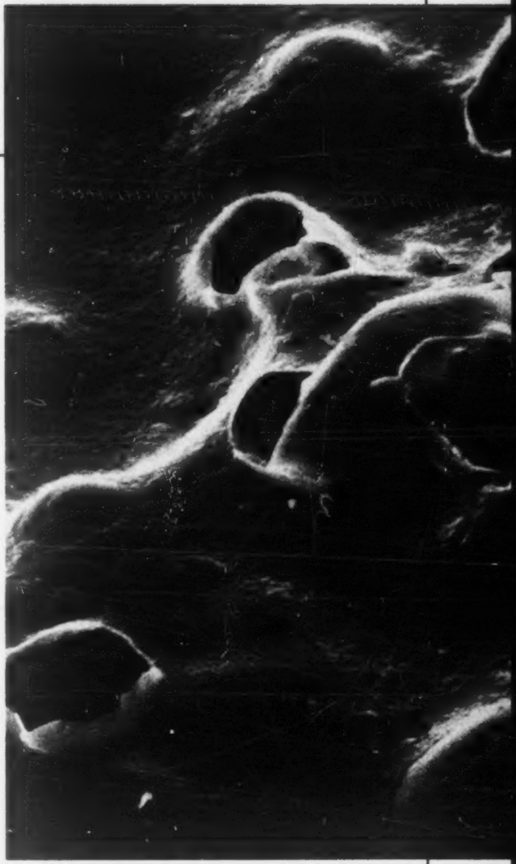

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70 Thin Films Get Thinner As Research Heats Up

Tim Studt, Associate Editor, R&D Magazine

The tremendous improvements that thin-film coatings contribute to semiconductors, optics, and machine tools are driving researchers to develop thinner, stronger, and a greater variety of thin-film materials. Although processing is more difficult for submicrometer thin films, gains outweigh the problems.

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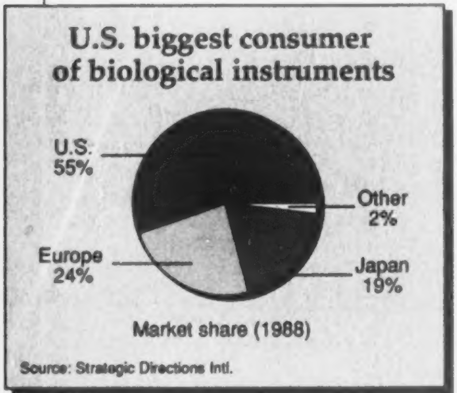
R&D BUSINESS

Human genome R&D pushes equipment sales

THE MOLECULAR BIOLOGY equipment market will grow more than 22% annually to exceed $450 million by 1993, according to analyst Alexandra Straus of Strategic Directions Intl., a Los Angeles-based market consulting firm.

The U.S., which accounted for 55% of 1988 sales, will remain the largest market sector with most instruments used for human genome R&D. "However, Asian and European markets will grow faster," says Straus.

U.S.-based manufacturers, such as Applied Biosystems, DuPont, and Hewlett-Packard (with its purchase of Applied Protein Technologies), dominate the molecular biology equipment market, which includes such instruments as DNA sequencers and synthesizers. ☐



Source: Strategic Directions Intl.

U.S. human genome research will retain its position as the largest market sector for automated molecular biology equipment at least through 1995, says market analyst Alexandra Straus.

Control Data tests export laws with Soviet computer order

THE SINCERITY of the Bush Administration's Malta summit support of nuclear-safety research is being tested by Control Data. The Minneapolis-based company has submitted a mainframe computer order from the Soviet Union to the U.S. Dept. of Commerce (DOC) for export approval. The computers are intended for Soviet nuclear research.

Current U.S. trade law prevents export to the Soviet Union of computers that can process more than 78 Mbit/sec. Each of the six Cyber 962-11 computers that Control Data wants to sell can process 435 Mbit/sec.

Control Data already has exported this same mainframe model to China for weather research. DOC performance restrictions for China are 550 Mbit/sec. "China is not seen as a military threat," says Control Data spokesman David Lindsey.

Soviet researchers plan to use the mainframes to analyze the safety standards of existing nuclear plants, assist in the design of new plants, simulate accident scenarios, and help in the decommissioning or renovation of many plants, including the Chernobyl complex and the superheating reactor at Beloyarsk which has been shut down.

The 962-11 computers exceed anything Soviet nuclear researchers currently have. Soviet officials say their existing reactors are safe, but "it is not enough to demonstrate safe operation," says Eugene Adamov, director of the Soviet's R&D Institute of Power Engineering (RDIPE), Moscow.

The Soviets want to use these computers to modify the design of their reactors to better tolerate malfunctions. The computers will be located at RDIPE, the Hydropress Experimental Design Bureau (Podolsk), the Special Machine Building Design Bureau (Gorkij), and the Chernobyl Complex Expedition (Moscow).

U.S. national security concerns were considered in this sale and safeguards have been identified, including on-site monitoring by U.S. personnel according to James Ousley, president of Control Data's Computer Products Group.

Control Data representatives express confidence that DOC export approval can be obtained by late spring 1990. An application then would be submitted to the multinational Coordinating Committee for Multilateral Export Controls (Cocom).

If the U.S. approves the sale, Cocom most likely also would give its approval. This would have the computers in place and operating by late summer 1990. *—Tim Studt*

Soviet researcher Eugene Adamov says "Computers [from the U.S.] will enable us to bring our nuclear reactors up to international safety standards."

Japan picks the world's 10 best companies

1989	1988		Hdqtrs.
1	1	IBM	U.S.
2	2	Glaxo Holdings	UK
3	9	Royal Dutch/ Shell	Neth., UK
4	7	Exxon	U.S.
5	45	Dow Chemical	U.S.
6	10	General Motors	U.S.
7	5	British Telecom	UK
8	6	Ford Motor	U.S.
9	4	Digital Equip.	U.S.
10	45	American Home Products	U.S.

FOR THE FOURTH year in a row, IBM was ranked as the world's best company in an annual survey conducted by Nihon Keizai Shimbun Inc., publisher of the English-language *Japan Economic Journal*.

Items such as asset base, profitability, stability, and financial performance were considered in ranking companies in 20 countries.

High-tech electronic, pharmaceutical, chemical, and multinational automotive companies dominated the survey's upper rankings.

You'll Be Better Paid in 1990, Despite the Shaky Economy

People in R&D enter the 1990s with fatter paychecks, thanks mostly to increasing age and experience.

By Robert R. Jones, Executive Editor, R&D Magazine

FOLLOWING A YEAR of weak corporate earnings with a shaky world economy, most workers in research, development, and quality assurance are better off—or, at least, no worse off—than they were 12 months ago.

A careful look at this year's industry profile, based on an exclusive survey of nearly 3,800 readers of *R&D Magazine*, reveals an R&D work force that is decidedly different from the one that entered the previous decade.

Compared with the R&D work force of 1980, workers now in research, development, and quality assurance are older, more knowledgeable, and far more well-to-do.

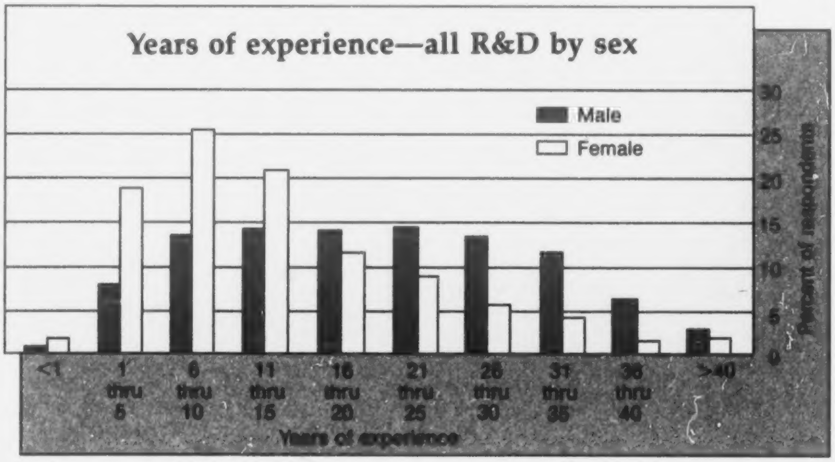
The salary range for R&D workers continues to expand, as it has for more than 15 years, with the upper end climbing while the lower end remains essentially stationary.

Only 4% of our 1980 respondents listed an annual salary of $46,000 a year or more. The most populous single salary span that year was $25,000 through $27,999. (In those years our salary scale covered $3,000 spans. As the salary range expanded, the charts became so crowded that we changed to the $5,000 spans that we use now.)

By 1985, the portion of respondents earning $45,000 or more was 35.1%, with the most populous span being $40,000 through $44,999. Today, 60.8% of our respondents report annual salaries of $45,000 or more, an increase of 56% in 10 years. The most populous span (with 13.2%) is $50,000 through $54,999.

The median income for this year's respondents is $49,632, up 4.7% from last year's $47,417. This increase is only half as large as last year's (9.2%), but stands well above 1988's increase of 0.42%.

The 1989 increases, now in effect, follow a year with a relatively low inflation rate. For nearly half of the respondents, their salary increases more than kept them even with inflation.


Years of experience—all R&D by sex

$30 billion payroll

With these rising figures you continue to be part of an affluent demographic segment. Workers in research and development in the United States will draw a total paycheck in 1990 of $29.8 billion, up impressively from $24.1 billion in 1985.

The biggest salary increases went to chemical engineers, with 40.8% getting raises of 6% or more last year. They were followed by biologists (40.0%) physicists (34.5%), and chemists and mechanical engineers (tied at 33.8%).

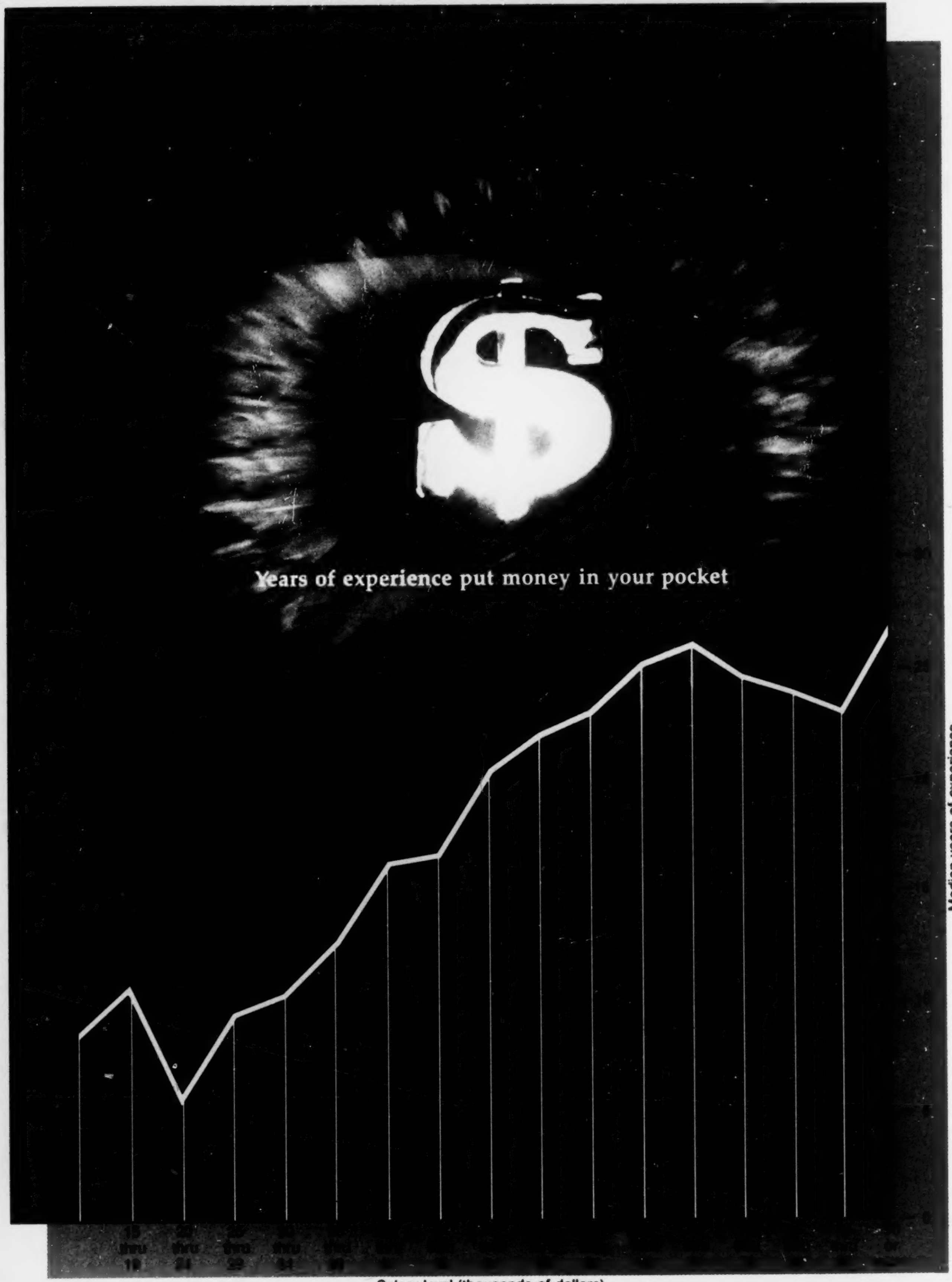
Mathematicians were at the low end of the group with none reporting a salary increase of 10% or more, although nearly three fourths of them reported increases of 6% through 9% (see accompanying table).

The percentage of respondents receiving no salary increase last year (9.2%) is similar to 1989's (9.3%) and far below the three preceding years, which peaked with 16.5% getting no raise in 1987. Remember, however, that this group includes a substantial percentage of new hires.

Aero engineers lead

Looking at median salaries by discipline, aeronautical engineers held onto first place for the third year in a row despite a 2.4% decrease from last year's reported median. Aeronautical engineers also top our charts for both age and experience, with one in eight being older than 65.

Mathematicians (up 17.6%) and industrial engineers (up 21.9%) made the strongest median salary gains over



Years of experience put money in your pocket

Veteran scientists and engineers earn rewards for years spent doing research and development.

last year. As did aeronautical engineers, metallurgists reported lower salaries this year (median down 0.5%), falling three places in the discipline rankings chart.

In last year's report, we called attention to the $19,000-plus span between the median incomes of industrial engineers ($38,125) and aeronautical engineers ($57,500). This year, industrial engineers did a lot of catching up, while aero engineers slipped a little.

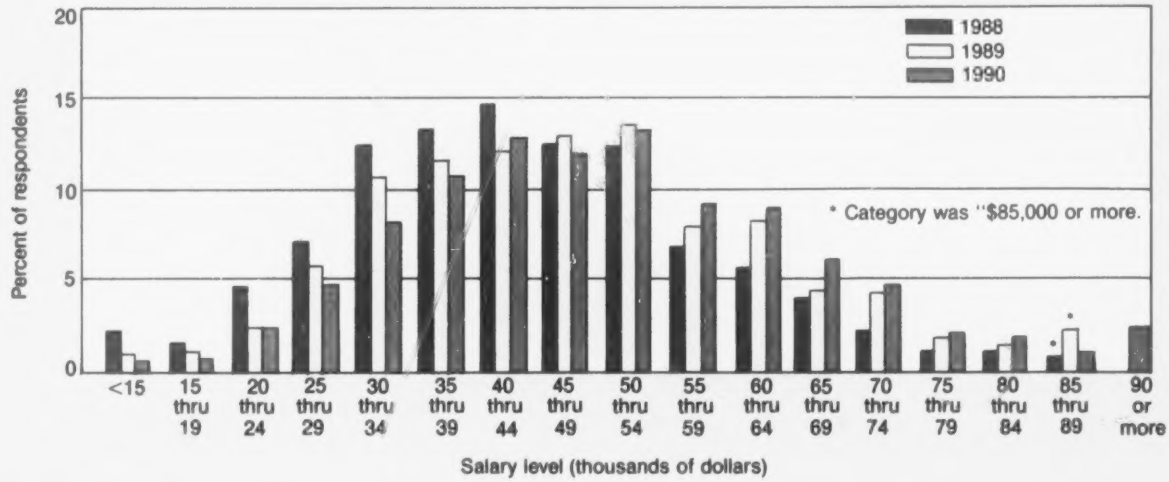
Now the gap is down to $9,663, but even with that adjustment, median salaries for aero engineers still are 20% greater than those for industrial engineers (and biologists, who now are at the bottom in the ranking).

Throughout the 1980s, the median age of respondents to our survey has moved steadily upward, with the median age in 1980 being 40.4 years, in 1985 42.0 years, and now 44.4 years.

Dollars for experience

Likewise, the median years of experience for our respondents has increased from 15.4 years in 1980 to 16.5 years in 1985, and now stands at 18.7 years.

Salary levels for all R&D (three years compared)



All disciplines compared	1989 salary raise amount						1990 salary range			Years with present employer		
	None (%)	Less than 2% (%)	2 thru 5% (%)	6 thru 9% (%)	10 thru 13% (%)	14% or more (%)	Median	<$15,000 (%)	>$90,000 (%)	Median	<1 (%)	>36(%)
Aeronautical engineer	3.3	4.9	63.9	13.1	11.5	3.3	$56,111	—	3.2	9.4	3.2	—
Biologist	5.0	2.0	53.0	27.5	7.0	5.5	46,315	0.5	1.5	9.3	3.9	1.0
Ceramist	7.9	—	66.7	19.0	3.1	3.3	53,250	—	—	5.7	6.3	3.2
Chemical engineer	7.9	0.4	50.9	32.1	6.1	2.6	52,931	0.4	3.4	8.8	5.6	1.9
Chemist	8.8	1.8	55.6	25.5	5.8	2.5	48,312	0.8	2.4	10.2	4.0	1.0
Electrical engineer	12.2	2.8	52.9	22.0	6.5	3.6	50,978	1.0	1.8	9.2	4.1	2.3
Geologist	13.3	6.7	50.1	29.9	—	—	51,250	3.3	3.1	8.1	6.5	—
Industrial engineer	5.7	—	65.7	20.0	2.9	5.7	46,500	2.7	—	11.1	2.7	5.4
Mathematician	5.5	5.7	72.2	16.7	—	—	49,999	—	—	15.0	—	—
Mechanical engineer	11.5	1.6	53.1	25.2	5.5	2.8	49,280	—	1.0	7.9	5.2	2.4
Metallurgist	7.5	3.7	65.8	18.2	3.2	1.6	51,928	0.4	0.6	9.1	3.1	1.0
Physicist	9.5	3.0	53.0	26.3	6.2	2.0	54,500	0.3	2.9	10.2	2.3	1.6

Increases in rate of pay*

Amount of increase	1990	1989	1988	1987	1986	1985
	Percent of respondents					
None	9.2	9.3	14.5	16.5	11.3	9.3
Less than 2%	2.1	5.3	6.3	4.3	3.6	2.9
2 through 5%	54.9	54.8	49.8	39.2	37.1	36.6
6 through 9%	24.7	22.2	21.7	30.8	36.3	37.6
10 through 13%	5.9	5.6	4.7	6.0	8.3	10.1
14% or more	3.2	2.7	3.0	3.2	3.3	3.6
Ahead of inflation	46.5	44.2	46.0	79.2	60.1	63.3

* Granted in preceding year for year shown

Discipline rankings by median salaries

Rank			Median salary		Percent
1990	1989	Discipline	1990	1989	change
1	1	Aero. engineer	$56,111	$57,500	-2.4
2	3	Physicist	54,500	51,087	6.7
3	4	Ceramist	53,250	50,500	5.4
4	7	Chem. engineer	52,931	49,100	7.8
5	2	Metallurgist	51,928	52,205	-0.5
6	4	Geologist	51,250	50,500	1.5
7	6	Elec. engineer	50,978	50,185	1.6
8	11	Mathematician	49,998	42,500	17.6
9	8	Mech. engineer	49,280	48,900	0.8
10	9	Chemist	48,312	45,243	6.8
11	12	Indust. engineer	46,448	38,125	21.9
12	10	Biologist	46,315	43,846	5.6

When salary is correlated to experience (see accompanying chart), this premium for experience becomes more obvious. For this year's respondents with less than a year's experience, the median income is $32,083.

Median for those with one through five years is $35,132. For six through 10 years, it is $42,244, and so it goes, rising to a median annual salary of $54,423 for those with more than 40 years' experience.

The percentage of respondents with PhD degrees has moved from 27.6% in 1980 to 33.1% in 1985, and now stands at 31.6%. Biologists lead the disciplines in the percentage with a PhD, as they did in 1989. Physicists retain second place. More than half of the respondents in both of these disciplines have PhD degrees.

Geologists again are in third place, with nearly half of the respondents having doctorates. Mechanical engineers have the lowest percentage of PhDs at 10.9%.

When master's degrees and doctorates are considered together and the disciplines are ranked for advanced degrees, geologists and biologists are tied for the lead with more than 80% (80.7% and 80.6%) having an advanced degree.

Physicists are next in order at 75.1%, followed by mathematicians, 72.2%; ceramists, 71.4%; and aeronautical engineers, 71.0%.

In the second part of this report, we will look into the implications of some of the above conclusions and also report on the value of an advanced degree to its holder, relative salary scales of men and women, and the advantages or disadvantages in salaries for jobs in industry, government, or university. **R&D**

Age, years			Experience, years			Highest academic degree			
Median	<26 (%)	>65 (%)	Median	<1 (%)	>40 (%)	<BS (%)	BS (%)	MS (%)	PhD (%)
47.9	3.2	12.9	24.6	—	9.7	3.2	25.8	51.6	19.4
43.3	1.0	3.4	16.1	—	2.9	1.0	18.4	23.8	56.8
41.9	—	1.6	16.7	—	1.6	3.2	25.4	31.7	39.7
44.6	1.8	2.0	18.3	1.4	1.6	1.5	46.8	29.6	22.1
44.5	1.5	2.5	18.8	0.5	1.8	4.2	36.2	19.2	40.3
44.7	3.2	3.4	20.1	1.0	3.3	17.4	36.4	33.4	12.8
41.5	—	3.2	15.5	—	—	9.6	9.8	32.3	48.4
45.6	—	2.7	22.2	—	2.7	29.7	35.1	18.9	16.2
47.5	—	—	20.9	—	—	5.6	22.2	38.9	33.3
44.7	2.6	3.6	19.7	0.8	3.4	14.3	45.4	29.4	10.9
44.3	1.0	1.6	18.8	0.4	0.6	5.2	30.2	26.0	38.5
45.4	1.8	2.0	19.5	0.3	1.9	2.9	22.0	22.7	52.4

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Thin Films Get Thinner As Research Heats Up

Processing is more difficult for submicrometer thin films, but gains outweigh the problems.

*By **Tim Studt**, Associate Editor,* R&D Magazine

SUCCESS BREEDS success as the saying goes. The tremendous improvements that thin-film coatings contribute to semiconductors, optics, and machine tools are driving researchers to develop thinner, stronger, and a greater variety of thin-film materials.

Researchers now regularly use chemical vapor deposition (CVD), molecular beam epitaxy (MBE), and ion-bombardment processes to fabricate new materials and structures that offer vast improvements in properties over current materials.

The most dominant areas for thin-film research, other than semiconductors, are hard coatings, optical coatings, magnetic storage media, and high-temperature superconductors.

Submicrometer semiconductors

In semiconductor production, most companies are at the 1.5-to 2-μm thin-film structure level, more advanced firms are at 1.0 to 1.5 μm, and the most advanced ones are at 0.5 to 1 μm.

Going smaller than 0.5 μm poses special processing problems, according to Arnold Reisman, vice president of semiconductor research and technology at the Microelectronic Center of North Carolina (MCNC), Research Triangle Park.

He lists several problems that MCNC's industrial affiliates, which include IBM, say must be solved before production of sub-half-micrometer devices will be practical.

One problem involves high-frequency signals that cause the current in a wire to be carried on the wire's surface. In 0.5-μm ultralarge scale integration devices, this effect results in attenuation of the signal and degradation of the waveform.

The effect even occurs in high-temperature superconductors and is most prevalent in chip interconnections. Optical thin films are being tested as an interconnection material to eliminate the signal degradation.

A second problem involves tungsten deposits, which can grow on mask through-holes and cause electrical shorts.

Researchers at MCNC have developed an etching process that removes tungsten from the mask faster than from the substrate. This process allows you to remove all of the buildup on a mask while removing only a small amount from the substrate.

Another problem Reisman notes is that while contaminants in the ambient air, process gases, and process liquids can be filtered to less than 0.5 μm, processing equipment contributes particulates at sizes and levels that can affect product yield.

Most U.S. equipment producers don't have the resources to devote to solve this problem. Only large, vertically integrated Japanese companies, such as Nikon and Canon have the ability to fund research to eliminate this problem.

Lithographic light sources are another problem area for devices with less than 0.5-μm dimensions. "The 248-nm-wavelength xenon fluoride laser will enable us to build 0.25-μm devices," says Reisman.

But, to obtain smaller structures, 193-nm sources, such as those from argon fluoride excimer lasers, will be needed. However, 193-nm light quickly creates defects—radiation damage—in the quartz laser lenses. These defects diffuse the beam, making it difficult to maintain the necessary beam width.

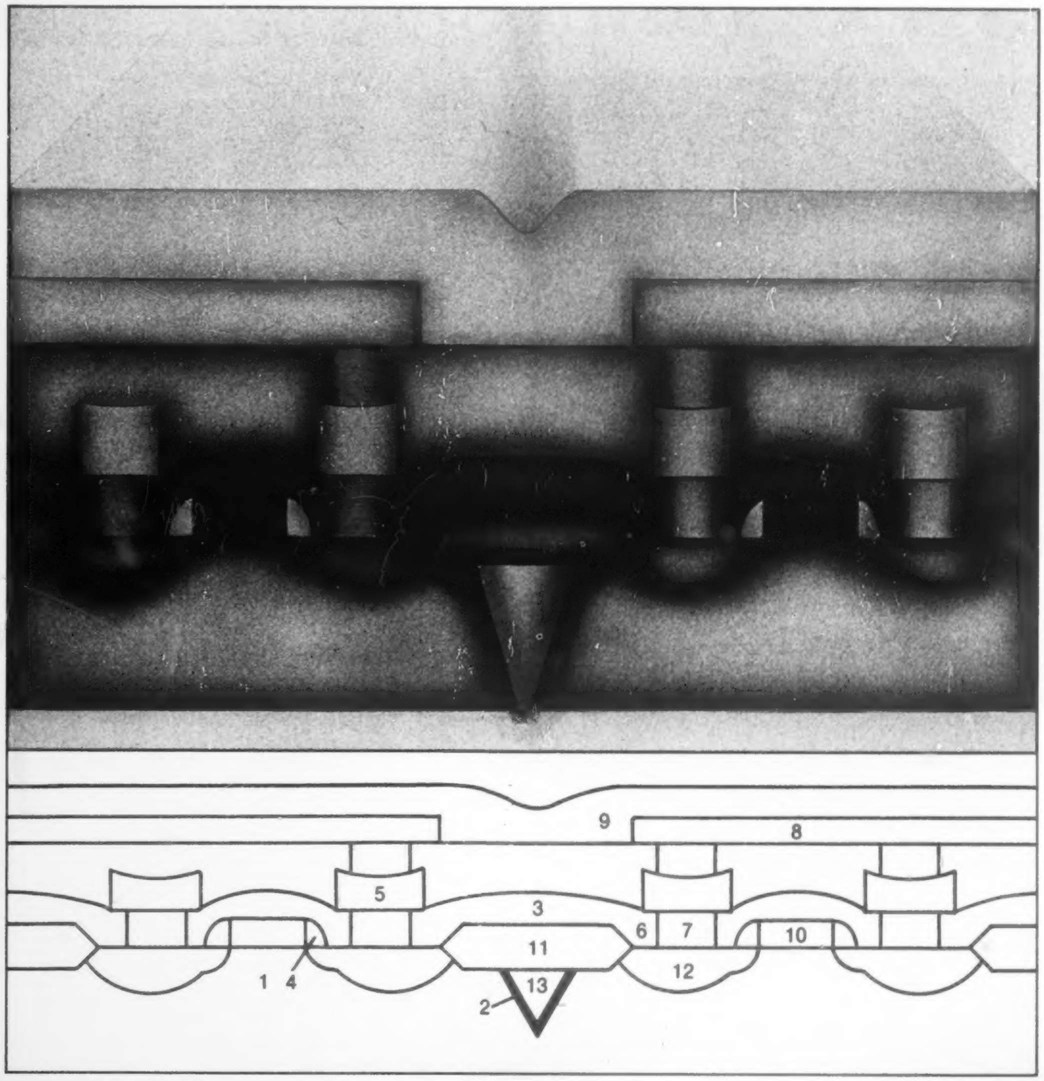
Tests at MIT's Lincoln Lab, Cambridge, reveal that these defects are permanent and do not anneal at room temperatures even after a year. Japan's Matsushita researchers design thin lenses that reduce light absorption to minimize the defects.

X rays can be used as a light source, but they also cause radiation damage that's hard to get rid of.

Processing materials

Current semiconductor intermetal processes provide a final dielectric topography that's smooth, but not perfectly flat. With new devices needing three or four levels of metallization, the one or two insulating layers between each pair of metal conductors must be absolutely flat.

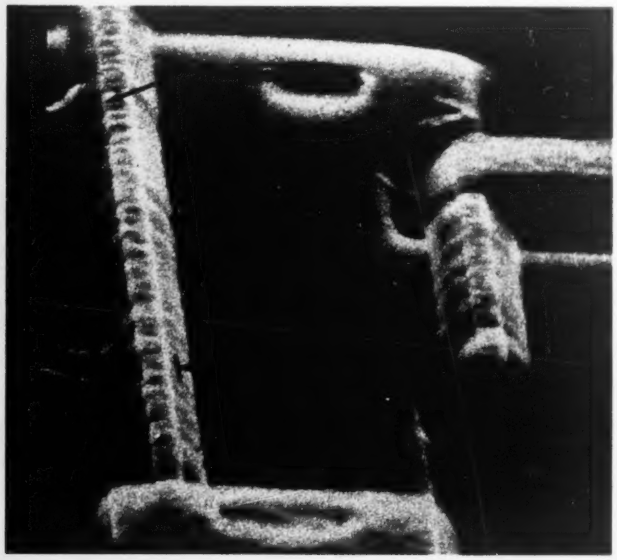
No current process provides complete flatness (planarization), but IBM, Sematech, and some Japanese companies have tried



The ever decreasing dimensions of thin film depositions in multilayer semiconductor circuits require continual development of new materials and deposition processes.

1. Epitaxial layer
2. Trench isolation
3. Planarized intermetal dielectric
4. Sidewall spacer
5. Metal 1
6. Interlayer dielectric
7. Tungsten plug
8. Metal 2
9. Passivation
10. Polycide gate electrode
11. Field oxide
12. Source/drain
13. Trench

Figure courtesy of Applied Materials



IBM used electron-beam lithography to make this FET (left) which demonstrates basic feasibility of 10-Gbit memory chips.

The center of this clear polycarbonate disk (right) has OCLI's antireflection coating that also resists abrasion damage in the coated area.

to grind the layers to get flatness.

"A more elegant solution is to perform this process in a deposited etchback manner," says Patrick Thomas, marketing director for advanced deposition technology at Applied Materials, Santa Clara, CA. "We deposit B_2O_3 that flows as it's being deposited and can give a 100-µm layer with only a 2- to 3-deg slope."

TEOS (tetraethylorthosilicate) has been used to deposit advanced semiconductor dielectrics because of its more uniform coating ability, while silane (SiH_4) has been the traditional source material for production coatings. However, the complexity of submicrometer devices is forcing researchers to replace silane with TEOS.

Hard coatings

Most hard coatings are based on nitride and carbide thin-film coatings. A new material being developed is titanium aluminum nitride.

"The reason this material is so interesting is that it keeps the cubic structure of titanium nitride, but has much higher oxidation resistance," says William Sproul, a researcher at Northwestern University's Basic Industry Research Laboratory, Evanston, IL.

Titanium aluminum nitride can be used in high-temperature wear applications where you're concerned about converting from a nitride to an oxide. In the 50%-50% titanium-aluminum ratio, the coating is harder than either TiN or AlN.

Sputtering is an ideal process for depositing these coatings because maintaining alloy ratios is easier than with other processes. An evaporative process, for example, would vaporize the aluminum in the target well before the titanium is vaporized.

Although cutting tools have had monolayer TiN and TiC thin-film coatings for several years, advancements in coating adhesion are improving these products.

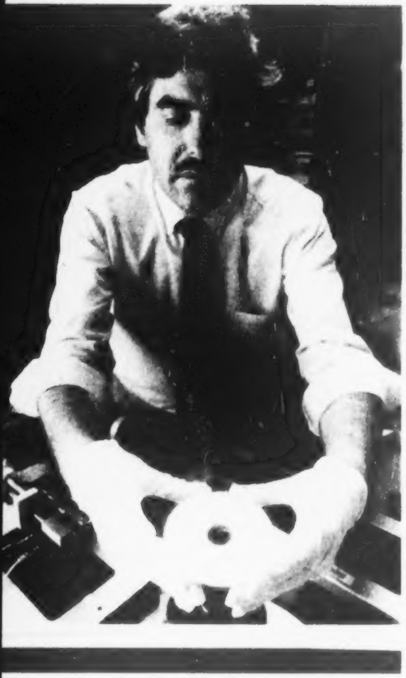
Kennametal Inc., Latrobe, PA, makes cutting tools that have between two and 13 thin-film coatings. The tool substrate (WC) has alternating layers of TiN, Al_2O_3, and TiCN. By controlling the use of these materials, tools can be designed for specific applications. The abrasion resistance of TiC and TiCN, Al_2O_3's chemical inertness and insulative characteristics, and TiN's lubricity are considered when designing these tools.

Optical coatings

Antireflection, abrasion, and protective thin films commonly applied to glass can also be applied to flexible plastic optics in submicrometer to 50-µm thicknesses.

Optical Coating Laboratory Inc., Santa Rosa, CA, uses ion beams to deposit materials on plastics at or near room temperature, which eliminates optical distortion and increases the coating's durability.

One application for this process is as a laser rejection coating for protective eyewear. The coating performance, 10^{-3} to 10^{-4} rejections, is limited from the ideal performance of 10^{-5} to 10^{-6} rejections by stress levels in the plastic substrate, not



IBM scientist Ian Sanders holds a thin-film coated magnetic disk etched with 0.5-µm-wide circular tracks and capable of holding up to 10-Gbits of data.

Putting the film down

SELECTING the best deposition technique from the many available can be confusing. Here's a rundown of various methods and what's new with them:

- **PVD (physical vapor deposition) applies films to substrates by evaporating or sputtering a source (target) and allowing the material to deposit on a substrate.**

To form compounds, both sputtering and evaporation can be performed with a reactive gas in an activating plasma.

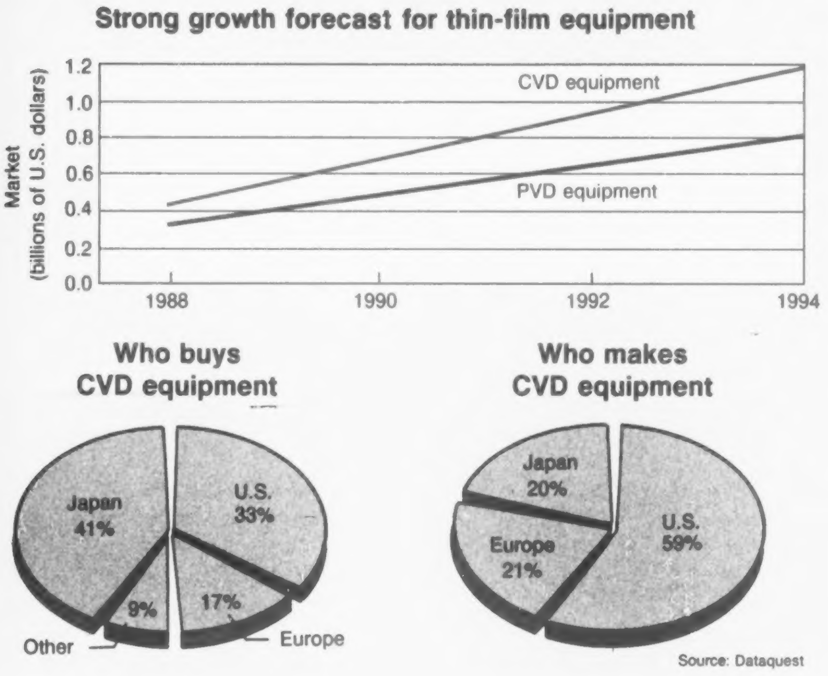
Ion plating is similar to sputtering, except the susbstrate is electrically biased, which causes a working gas such as argon to ion bombard the substrate, improve the coating adhesion, and change its surface microstructure.

Ion implantation uses an ion beam accelerator to bombard a substrate with high-energy ions to dramtically change the surface characteristics of a substrate target. Electron cyclotron resonance (ECR) implantation provides improved control in this process.

- **CVD (chemical vapor deposition) flows gases over a heated substrate where they react to form a thin film. Most CVD processes are performed in vacuum, but newer methods allow coating in low- or atmospheric-pressure environments.**

Plasma-enhanced CVD (PECVD) processes can be used with RF- or photon-excited methods.

- **Spin-on deposition drops liquid precursors on a spinning substrate for even distribution. This is followed by pyrolysis to cure the film. Spin-on methods can be performed in vacuum or nonvacuum environments and with materials such as glass and metal-organics.**
- **Dry-etch processes are replacing wet-etch methods due to better control, processing ease, and, most importantly, less pollution. Processes in use or development include reactive ion etch (RIE), ECR etch, magnetically enhanced ion etch (MIE), and sputter etch.**

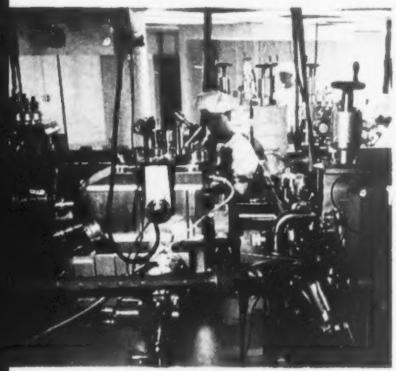

Strong growth forecast for thin-film equipment

Who buys CVD equipment

Who makes CVD equipment

Source: Dataquest

U.S. companies dominate the CVD equipment market with more than $260 million in sales in 1988. However, that market share is expected to erode over the next several years according to Dataquest analysts.



Univ. of Illinois' MBE facility eliminates air contaminants by transferring samples in UHV tubes between film growth chambers.

by thin-film materials or processes.

A 20% improvement in oxygen permeability over existing coatings also allows these coatings to be applied as protective barrier layers in packaging products.

Magnetic media

IBM's Almaden Research Center, San Jose, CA, recently demonstrated 1-Gbit/in^2 storage media capability. This tenfold improvement over existing systems was made with a conventionally sputtered cobalt-platinum-chromium coating about 200-Å thick onto a 100-Å-thick chromium coating.

This system uses a 125-Å-thick carbon overcoat. Because this is only a third of the thickness of conventional protective coatings, more research is needed to determine if it provides adequate protection.

Research also is being performed on magnetoresistive recording heads, which could replace conventional inductive heads. "The potential for structures with very high resistance changes exists, which transducers in the future will rely on to generate readback signals," says Ian Sanders, manager of IBM's magnetic storage research.

Superconducting thin films

Various thin-film approaches are being used to fabricate high-temperature superconducting (HTS) materials. An integrated MOCVD (metal-organic CVD) process that continuously deposits yttrium-barium-copper HTS thin films on flexible fibers has been developed by researcher Jack Lackey at Georgia Institute of Technology, Atlanta.

By depositing the superconducting material on a flexible fiber Lackey can bypass the basic brittleness problems of HTS materials and make wires that are flexible.

"Yttrium-based superconductors have fewer processing problems and are closer to applications," says Antonio Mogro-Campero at General Electric's Corporate R&D, Schenectady, NY. Thallium films have the highest superconducting temperature (125 K) but are very hard to process due to thallium's tendency to migrate out of its deposition layer after thermal processing.

Depending on the application, Mongro-Campero uses coevaporation, sputtering, chemical-precursor, or MOCVD to deposit HTS materials.

Integrating systems

By connecting several vacuum deposition processes together, improvements in the quality and characteristics of thin films can be obtained by eliminating the potential for air contamination between processing steps. The MBE Center at Univ. of Illinois, Champaign, uses seven interconnected MBE chambers with a UHV racetrack that allows researchers to move their test materials from one chamber to another without breaking a vacuum.

A process developed by engineers at Nippon Steel Corp., Kawasaki, Japan, combines plasma-assisted CVD with sputtering, ion plating, and ion bombardment for deposition of multiple thin films on a continuous metal coil. This process allows deposition of improved corrosion-resistant coatings, electrically insulated coatings, and a wide range of abrasion-resistant coatings.

Measuring thin films

Few improvements in thin-film measuring methods have been made during the past decade. Routine measurements include:

- x-ray diffraction to determine what phases are present
- Auger and SEM to determine microstructure, surface structure, grain size, and porosity
- ESCA or XPS for surface chemical analysis
- microindenter for hardness.

Most product-specific test methods require sophisticated equipment and highly trained personnel to operate them. These limitations don't lend themselves to development into generalized analytical products. **R&D**

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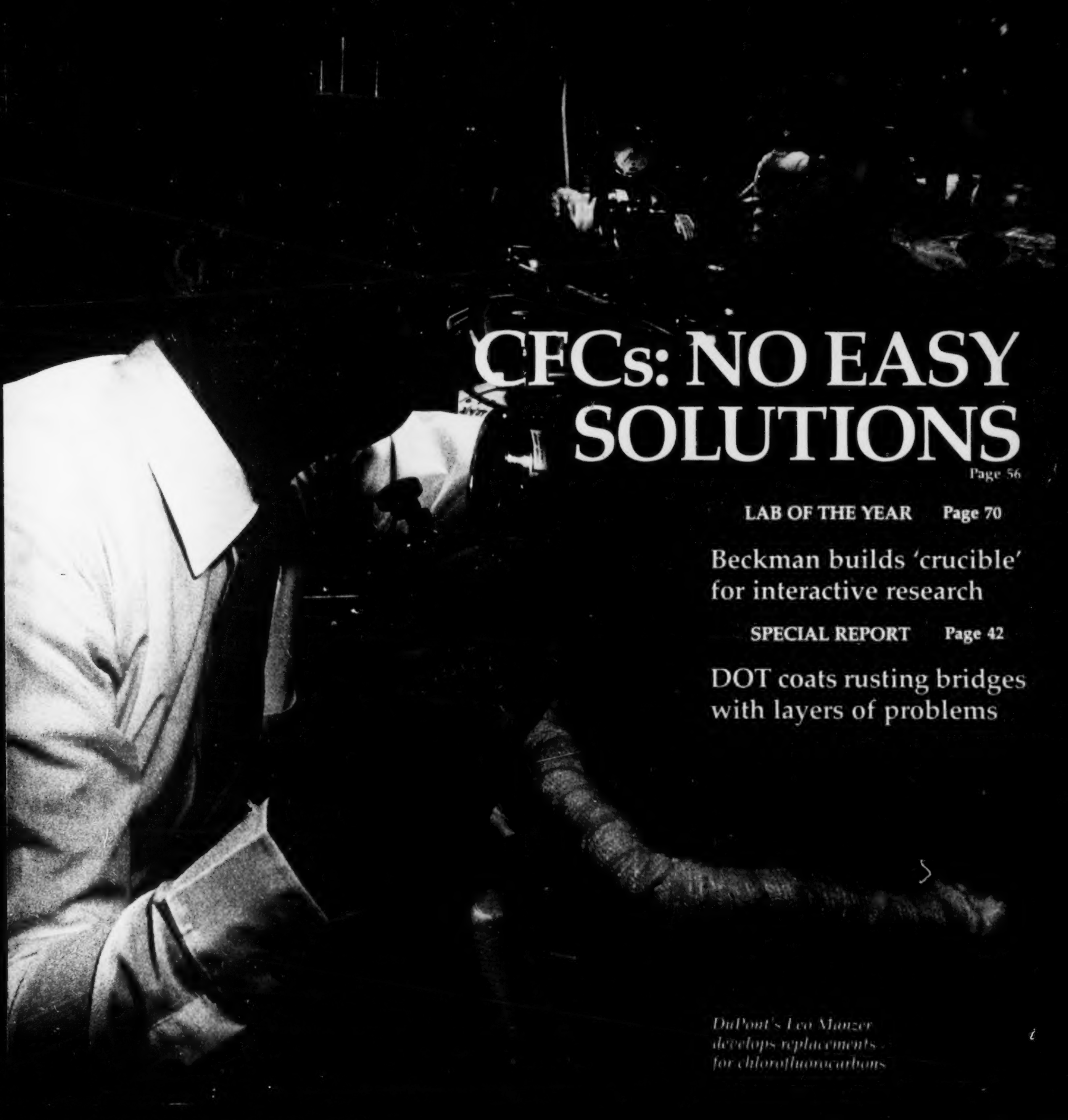
R D

Research & Development



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DOT coats rusting bridges with layers of problems

DuPont's Leo Manzer develops replacements for chlorofluorocarbons

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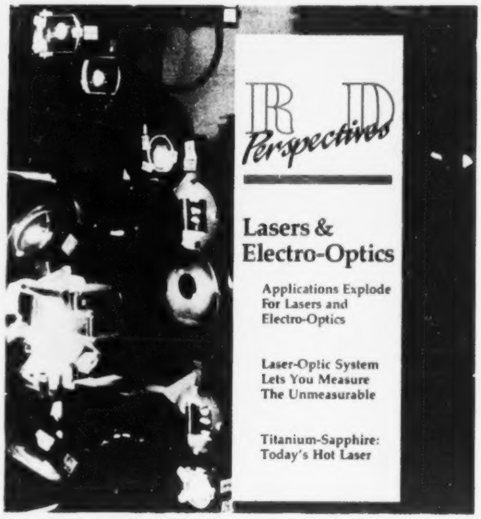

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Leo Manzer, a researcher at DuPont in Wilmington, DE, checks a system that produces experimental quantities of replacements for chlorofluorocarbons. See story on page 56. Photograph by Joe Nettis

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BUSINESS

U.S. research costs twice that of Japan's

IT COSTS substantially more for U.S. firms to finance long-term R&D projects than it does for Japanese companies, says Robert McCauley, a research officer and senior economist for the Federal Reserve Bank of New York.

McCauley calculates that for an R&D project with a 10-year payoff a U.S. company's average cost of capital is about 20% compared to about 9% for a comparable Japanese company.

"The driving factor for the U.S.-Japanese differences is the cost of equity," says McCauley, referring to the sustainable post-tax profit rate.

The other factor in the cost of capital, the cost of debt, actually is not much different in the U.S. and Japan. After adjusting for inflation and allowable tax deductions, both countries have debt costs between 1% and 2%.

The cost of equity for U.S. companies averages from 10% to 12%, while for Japanese firms it averages from 3% to 5%. The continuing emphasis by U.S. companies, and their stockholders, on short-term profits is the driving factor in this relationship.

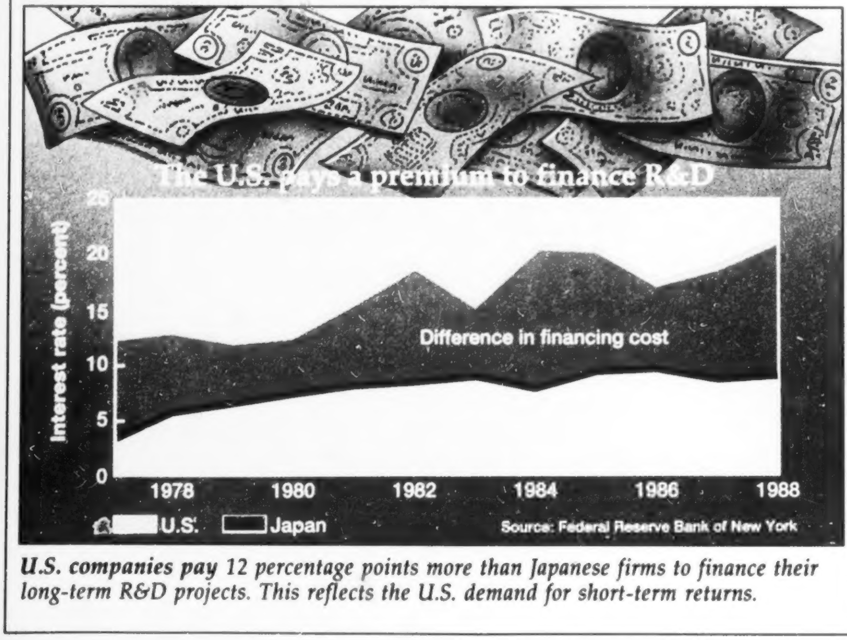
Most of the stock of large Japanese companies is held by other Japanese companies, often in the same industry group. These companies agree to hold the stock for long periods with few demands for returns, according to a recent U.S. Office of Technology Assessment report, *Making Things Better.*

This holds down the cost of capital for those Japanese firms and lowers the long-term financing cost of R&D projects and capital equipment.

The recent large drop in the Tokyo stock market combined with increasing foreign interest rates and lower U.S. interest rates will "narrow the gap slightly, but not much," says McCauley. "A [sustained] 20% drop in the Tokyo stock market would raise Japan's cost of capital less than 1%," he says.

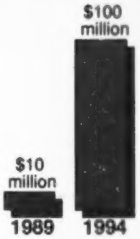
Government R&D tax credits can significantly affect R&D costs of capital. The combined equity and debt costs for German and Japanese firms are about the same, as are those for U.S. and UK firms.

However, because the UK and German firms don't have the 20% to 25% tax credits enjoyed by U.S. and Japanese companies, the costs of capital for a typical R&D project with a 10-year payoff is 4 to 5 percentage points higher for the German and UK firms. *—Tim Studt*



***U.S. companies pay** 12 percentage points more than Japanese firms to finance their long-term R&D projects. This reflects the U.S. demand for short-term returns.*

Capillary electrophoresis market to grow tenfold



THE CAPILLARY-electrophoresis instrument market will experience explosive growth over the next five years to $100 million a year, according to a recent study by Strategic Directions Intl., a Los Angeles-based market research firm.

The forecast includes only those instruments used in research and does not include the potential for other undeveloped applications.

Most CE systems now are sold in North America. Japanese and German researchers use gel electrophoresis instruments, which is a potential expansion market for CE systems.

Patents increase as U.S. cuts processing time

THE U.S. Patent and Trade Office issued a record 102,712 patents in FY89, up 22.3% over FY88 figures. PTO also reduced the average time to process a patent application to 18 months in 1989 from 25 months in 1983.

To catch up on the backlog of patent applications, an accelerated processing situation could account for up to 10% of the large atypical increase.

All global regions increased the number of U.S. patents they received. **Pacific Rim** countries received 22,611 patents, up 25.3%, with 20,907 going to Japanese residents, the largest number issued to a foreign country.

West European countries accounted for the second largest number of patents with 22,159, up 16.9%. West German (8,756), UK (3,378), and French (3,310) inventors had the largest share of this region.

East European inventors, while receiving 25.4% more patents in 1989, only accounted for 419 patents.

Third World countries also had a significant increase, up 28.8%, but they received only 684 patents.

U.S. inventors received 54,762 patents, an increase of 24.2%.

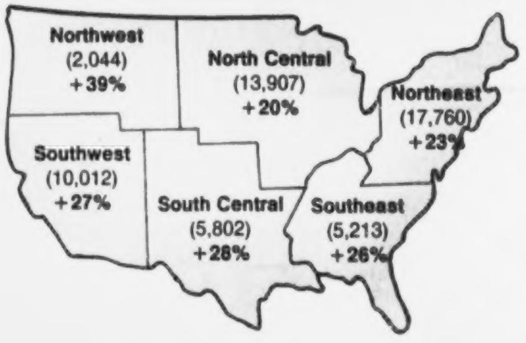
The PTO reported that the U.S. share of patents increased from 52.7% in 1988 to 53.3% in 1989, reversing a steady decline over the past 25 years.

California inventors received the largest number of patents (8,508), nearly twice the amount received by New York residents (4,527).

The demographics of patents within the U.S. correlates with the combined demographics of corporate headquarters locations and population.

A record number of patent applications (163,306) also were filed in FY89, up 10.2%, according to the PTO. ☐

Patents increase in every region from 1988 to 1989



Source: U.S. Dept. of Commerce

All regions of the U.S. had large increases in the number of patents issued in 1989.

In addition, the share of patents issued to foreign residents was reversed for the first time in more than 10 years.

Composite materials makers value quality more than R&D

COMPOSITES SUPPLIERS still feel that R&D is important, but not as important as it was in 1989 or 1988, according to Owens-Corning's annual survey of industry executives.

In 1988, executives cited R&D as the most important factor in their company's growth. However, in 1989 and again this year, product quality was listed as the most important factor. Although R&D was the second most important factor for the past two years, it continues to lose importance, being cited by only 18% of the respondents compared to 22% in 1989 and 30% in 1988.

The survey also noted that more companies (53% vs. 42% in 1989) are forming R&D partnerships with other companies, but fewer are working with foreign companies (23% vs. 68% in 1989).

"We're working in direct collaboration with domestic thermoplastic suppliers on [fiber-reinforced] product improvements," says Michael Griffith, vice president of R&D for Owens-Corning, Granville, OH. **R&D**

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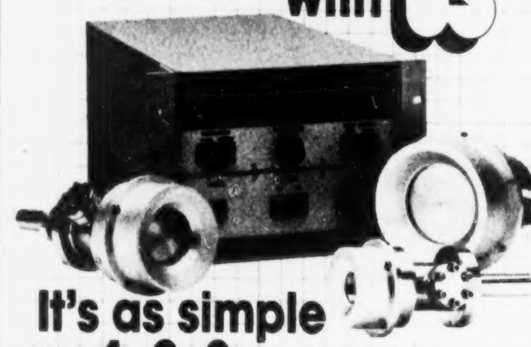

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CFCs

No Easy Solutions

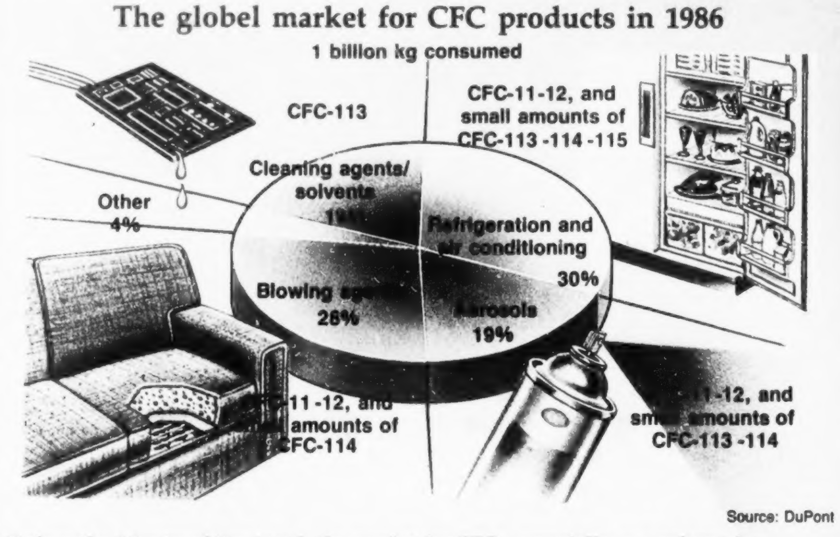
Researchers find no simple victories in their struggle to develop replacements for chlorofluorocarbons.

By Skip Derra, Associate Editor, R&D Magazine

LEO MANZER, a research manager at the central R&D facility of E.I. DuPont de Nemours & Co., marvels at the simplicity and versatility of CFC-113.

"This is a beautiful compound," the 43-year-old chemist says of CFC-113 ($C_2Cl_3CF_3$), which is used widely by industry as a solvent and parts degreaser. "It has great wetting properties—it doesn't bead up like water.

"It can get into all of those tiny nooks and crannies on printed circuit boards and clean off all of the residual flux," he says. "It doesn't harm surfaces. It has been used to clean sensitive gyroscopes and equip-

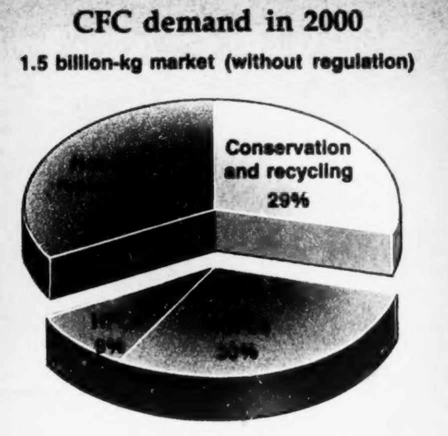


The globel market for CFC products in 1986

Source: DuPont

Before the Montreal Protocol, the market for CFCs, especially as a solvent in electronics, was growing as industry found the compounds to be cheap and easy to use.

Leo Manzer checks instrumentation in his lab at DuPont, where he heads a team of researchers who are developing CFC substitutes.



Source: DuPont

***Not-in-kind replacements,** stringent recycling programs, and alternate compounds will help to meet CFC demand in the year 2000, when the compounds will be outlawed.*

Industry will spend between $5 billion and $7 billion to convert to CFC substitute compounds.

ment on the space shuttle. This is a magical compound.

"But so far, there isn't a single compound that has been found as a replacement for 113," says Manzer, who heads DuPont's efforts into alternate CFC compounds. "That is the molecule everybody is looking for."

Replacing perfect compounds

Manzer and several researchers working under his direction are struggling to come up with replacements for what many people believe are perfect compounds—chlorofluorocarbons. Researchers at DuPont's Wilmington, DE, research facility and around the world feverishly are trying to find the right compound to replace such "magical" chemicals as CFC-113. So far, they have found "suitable" replacements, not magical compounds.

Next month, delegates from 45 countries will meet in London to sign a strengthened version of the 1987 Montreal Protocol that will probably phase out production of five of the most widely used CFC compounds and three Halon compounds by 2000.

The countries are doing this because CFCs destroy Earth's ozone layer, which shields us from the Sun's harmful ultraviolet rays. Continued destruction of the ozone layer eventually will destroy life on Earth, atmospheric scientists say.

But phasing out CFCs will be painful.

CFCs are used by 375,000 businesses to provide $28 billion of goods and services each year in the U.S. alone, according to the Alliance for Responsible CFC Policy, Washington, DC.

CFCs are the bloodline of refrigerators and air conditioners. They are an essential ingredient in manufacturing foam insulation, foam rubber, and foam for packaging. Many industries use CFCs to clean intricate parts and sophisticated computer chips and boards. Hospitals use the compounds as sterilants. Europeans use CFCs as aerosol propellants.

DuPont expects to spend nearly $1 billion during the next 10 years to research, develop, test, and market CFC replacement compounds. Manzer says industry worldwide will spend between $5 billion and $7 billion to convert to alternate compounds.

For Manzer, who received a BS from Univ. of Waterloo (Ontario), and a PhD in organometallic chemistry from Univ. of Western Ontario, London, the challenge is both exhilarating and exhausting.

"It's satisfying that our work will be commercialized in a very short time. What we do will have an impact on everybody in the world," says Manzer, who has worked at DuPont for 16 years. "There are not many times you can say that."

In Manzer's lab, 20 chemists and chemical engineers are working around the clock to come up with new processes to make the eight or so alternate chemical compounds identified as key replacements. Less than three years ago, the researchers were looking at a possible 600 compounds.

"There has been a lot of trial and

For refrigeration, compressed helium might be the answer

FOR YEARS Stephen Malaker, founder of Cryodynamics Inc., Mountainside, NJ, knew he had something special with his cryogenic cooler, but he couldn't talk about it.

Malaker couldn't talk about his modified Stirling engine because it was being used by the military in reconnaissance and night surveillance systems.

"It was so secret we couldn't get any publicity on it," says the 67-year-old physicist.

Now, with the battle being waged on CFCs, Malaker talks freely about his invention, which uses compressed helium as a refrigerant.

While the technology currently is being adapted for refrigeration, "it looks like we have a viable alternative," he says.

Most of the CFC alternatives bring with them tradeoffs in performance and energy efficiency and require modifications to existing refrigerators. It also has been difficult to find a lubricant for HFC-134a, a leading alternate refrigerant.

Malaker's approach to these problems has been to redesign a refrigerator to use compressed helium as the working fluid. Malaker says the modified Stirling engine has a number of advantages.

First, it is a proven technology developed in the 1960s during the Vietnam war and based on a number of patents. In addition to military uses, the system has been used on space shuttle and *Skylab* missions. Cryodynamics currently produces a compressed helium refrigeration system for truck transports.

Second, the modified Stirling engine is more efficient than other alternate systems, Malaker says. A home refrigerator using his system will need only 5 in.^{3} of helium compressed to about 200 psi.

"It comes to something like 75¢ of helium per home refrigeration system," Malaker says.

Cryodynamics is working with Admiral Co., Galesburg, IL, to develop a 20-ft^3 home refrigerator that will be cost competitive with what is on the market today. Automakers also are interested in adapting the technology for car air conditioning systems, Malaker says.

The refrigerator's most important attribute is that it will get away from using ozone damaging materials, such as CFCs and their first generation substitutes.

"Helium is totally benign," Malaker says. "It does not react with anything."

Stephen Malaker shows the compressed helium refrigerator that he could not talk about for years because it was being used by the military.

Cheryl Finley, a researcher at Allied-Signal, checks equipment used to manufacture CFC substitutes, which will help stabilize atmospheric chlorine levels.

Photo: IBM San Jose/Cindy Charles

A technician at IBM Corp. *removes storage disks that have been washed with a new water-based process. Electronics companies are finding that simple parts can be cleaned with substitute processes, but intricate circuits will require using HCFC solvents.*

error," the Canadian-born chemist says.

From these compounds (see chart) will come a host of blends optimized to mimic the CFCs they replace. But the scientists admit that these compounds are not a perfect solution to the ozone depletion problem. These are the first wave of alternate compounds that will help wean the world from CFCs.

As experts see it today, replacing CFCs will rely as much on changing business practices as developing new compounds. Satisfying the 2.5 billion lb/yr CFC demand will mandate a stringent CFC conservation and recycling program. It also will require industries wherever possible to use not-in-kind replacements, such as terpene-based cleaners and solvents and hydrocarbon and water blowing agents.

By 2000, nearly 40% of the market is expected to rely on hydrofluorocarbons (HFCs) and hydrochlorofluorocarbons (HCFCs), the replacement compounds that Manzer's group is working on.

Buying time

The alternate compounds will fill the most demanding applications and achieve two goals. They can help to stabilize the chlorine loading in the stratosphere, which is expected to peak at 4 ppb, and they buy time.

These alternate compounds "allow industry time to come up with non-chlorine-based technologies," says Mike Kurylo, who heads NASA's ozone research program while on leave from the National Institute of Standards & Technology.

But HFCs and HCFCs bring with them problems as well as solutions. The chemistry to make the compounds is two to four times more complex than that for CFCs, meaning they will be costly.

"Building a plant to make these compounds is equivalent to building three or four plants to make CFCs," Manzer says.

The complexity of the substitutes has had an effect on the materials used in their manufacture. The substitute compounds are designed to be less stable than CFCs and because of this they also are less robust during the manufacturing process.

This instability of the new compounds means they tend to decom-

"We would love to come in the lab tomorrow and say 'Eureka, we have the magic compound,'" says Manzer.

pose on catalyst surfaces, deactivating the catalyst. Part of the job of Manzer's group is to develop different types of catalysts that can stand up to the new molecules during their manufacture.

Environmental concerns also could spell doom to these compounds at any time.

HFC compounds, where hydrogen is used in place of chlorine, do not deplete the ozone but do contribute to the greenhouse effect. HCFCs, which use hydrogen as a trigger mechanism to make them degrade in the troposphere before they can reach the ozone layer, still deplete the ozone, though at a rate of 2% to 10% that of fully halogenated CFCs.

These attributes make the compounds unacceptable to some people.

"When you look at these chemicals," says Erik Johnson, coordinator of Greenpeace's ozone protection campaign, "you have to look at ozone depletion potential (ODP), at the waste stream involved, the greenhouse gases, and the toxicological problems. You have to go the whole nine yards."

Promising chemicals and technologies are on the horizon, such as the use of fluoroethers and technologies like the compressed helium refrigerator. But these technologies either require changing infrastructures or cannot be developed in time to meet the Montreal Protocol deadline.

"We would love to come into the lab tomorrow and say 'Eureka we have the magic compound,'" says Manzer. "But nobody has found it yet."

The substitute compounds are not the perfect replacements, says Bernie Sukornick, 62, director of R&D for Allied-Signal's Fluorocarbon Div., Buffalo, NY, the second largest U.S. producer of CFCs. "But they are a damn good direction in which to go.

"You don't invent molecules overnight," Sukornick adds. "Especially ones that have zero ODP and very little greenhouse effect."

Back to the future

All of the alternate compounds being worked on today were first discovered in the 1920s and 1930s. It was during this period when a team of researchers headed by Thomas Midgley at General Motors discovered CFCs.

These alternates then were refined during the 1970s, when the first scientific data linking CFCs and ozone depletion were published. Making the substitute compounds, not discovering them, is the challenge today.

"It seems like we are going to make

Half the battle is getting out of the CFC bias

RESEARCHERS trying to find alternates to CFCs face a major challenge just in eliminating the notion that CFCs are the perfect compound.

For product engineer Bill Kopko, York Intl. Corp., York, PA, getting out of this bias meant going to the company library and burying himself in vintage technical reports.

"I wanted to see what people were looking at [as replacement refrigerant compounds] in the 1920s and 1930s—pre CFCs," Kopko says. "The researchers then didn't have any preconceived notions, they were trying anything that could be used."

What Kopko found was a 1937 patent for halogenated methyl ethers issued to Harold Booth and assigned to Westinghouse, along with data on dimethyl ether and cyclopropane compounds. Some of these compounds have thermodynamic properties similar to CFCs and have a relatively simple structure, meaning they might have good cycle efficiency.

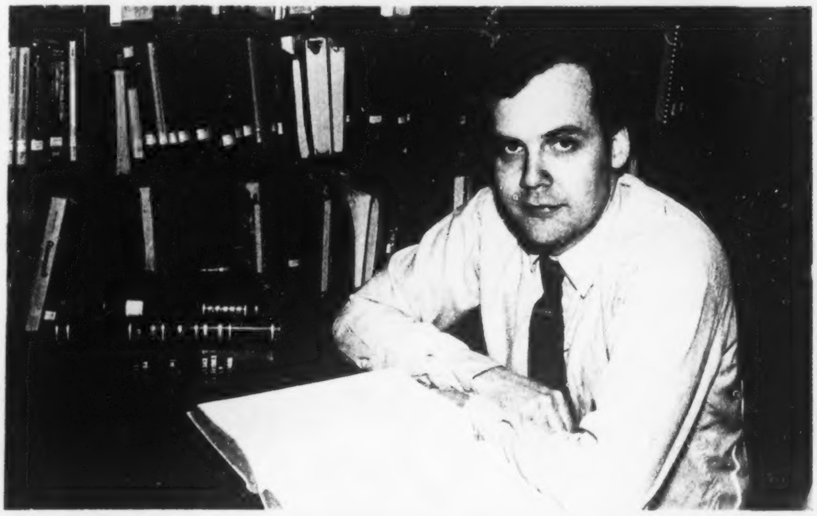
"There is enough information to show that some of these compounds are reasonably stable and have low toxicity," Kopko says.

For example, a difluoromethyl fluoromethyl ether compound has a boiling point—a key property for refrigeration—that comes close to CFC-11. A bis-difluoromethyl ether has essentially the same boiling point as CFC-114, Kopko says.

The U.S. Navy is interested in a bis-difluoromethyl ether compound as a substitute to CFC-114 in its refrigeration systems and has contracted with the National Institute of Standards & Technology to test the compound.

Although promising, fluoroethers are a long way from commercialization. But Leo Manzer, who heads DuPont's research into CFC substitutes says all technical problems aside, the compounds could be second generation replacements if their costs aren't prohibitive.

Whether fluoroethers are the magical compound chemists are looking for or not, Kopko's work illustrates that finding a replacement for CFCs might be a matter of perspective.



***Bill Kopko** at York International Corp. studies vintage technical reports at the company library to see what chemists in the 1920s were working on before CFCs were developed.*

'It seems like we are going to make great advances and end up back where we were in 1930,' says NIST's Didion.

great advances and end up back where we were in 1930 [with flammable refrigerants]," says David Didion, a mechanical engineer at NIST, who tests alternate compounds for refrigeration and air conditioning systems.

Of all CFC uses, refrigeration and air conditioning will present the most problems because existing systems are engineered around CFC-12. This means the substitutes must match the operating properties of CFCs so they can be used in the $135 billion of existing equipment that employ CFCs.

The mess with oils

Developing oils and lubricants that will allow the new compounds to be used in the pressure cycles of a refrigerator or air conditioner is critical. With HFC-134a, a key replacement for CFC-12, one problem is developing a miscible oil.

DuPont, Allied-Signal, ICI, and Atochem say they have proprietary lubricants that look promising for substitute refrigeration compounds. But some researchers are unconvinced.

"The engineering problems associated with HFC-134a and HCFC-123 are horrendous," says NIST's Didion. "Companies are spending tons of money developing these compounds, and it is not clear at all that 134a has an oil yet," he says.

Modifications to existing equipment also will be needed to use the alternate compounds in these systems. Researchers already have encountered

A biomedical scientist at General Motors exposes cell cultures to HFC-134a, a key substitute for CFC-12 used in car air conditioners, to determine the compound's toxicity. Design changes to automobiles will be required before HFC-134a can be used.

What's in and what's out in CFCs

	Compound	Lifetime (years)	Ozone depletion potential (avg)	Global warming potential (avg)	Primary uses
WHAT'S IN	HCFC-22	15	0.05	0.34	Air conditioning, refrigeration, foam packaging
	HCFC-123	2	0.02	0.02	Refrigeration, insulating foams, solvents
	HCFC-124	7	0.02	0.1	Air conditioning, insulating foams
	HCFC-141b	8	0.1	0.09	Insulating foams, solvents
	HCFC-142b	19	0.06	0.36	Insulating foams, solvents
	HFC-125	28	0	0.58	Refrigeration
	HFC-134a	16	0	0.26	Refrigeration, air conditioning
	HFC-152a	2	0	0.03	Insulating foams, aerosols
WHAT'S OUT	CFC-11	60	1	1	Insulating foams, refrigeration, air conditioning
	CFC-12	120	1	3	Refrigeration, air conditioning, insulating foams
	CFC-113	90	0.8	1.4	Solvents
	CFC-114	200	0.7	3.9	Foam packaging, aerosols
	CFC-115	400	0.4	7.5	Refrigeration

Source: World Meteorological Organization 1990 report

***While HFC and HCFC** compounds are not entirely benign, they cause considerably less damage to the ozone and contribute less to the greenhouse effect than the fully halogenated compounds they replace because of a shorter atmospheric lifetime.*

The best substitutes for foam blowers are HCFCs, but legislative action could eliminate their use.

problems with swelling gaskets and seals, and with reactions of the new compounds to the epoxies that coat the motors.

"Little by little, they are finding that they can use this epoxy or that epoxy, this gasket or that gasket," Didion says. "Little by little the problems are being solved."

Matching the properties of CFCs is especially crucial for the automotive users because not a lot of leeway exists to modify air conditioning systems to run on the alternates. Also, by 2000, nearly 75 million cars with air conditioners designed around CFC-12 are expected to be on the road.

Blends of two or three alternates are being developed to come as close as possible to matching the thermodynamic properties of CFC-12. DuPont has formulated a blend of HCFC-22, HFC-152b, and HCFC-124 as a replacement for CFC-12 in car air conditioners. Allied-Signal has a similar blend of alternate compounds.

Trouble with blends

"None of these compounds are drop ins," says Jerry Stofflet, assistant director for automotive emission control of the environmental activities at General Motors, Warren, MI.

"All of them require changes to the automotive systems," Stofflet says. "The big problem with blends is that you cannot recycle them on the spot. You will have to put them in a tank and ship them across state lines, and that creates more problems."

Stofflet says 28 design changes will be needed for GM cars and trucks to use the new compounds. He says the changes will be unnoticeable to consumers, although costs are expected to rise.

Electronics companies have ambitious programs for phasing out CFCs. Motorola Inc., Schaumburg, IL, plans to phase out all CFC emissions by the end of 1992. IBM Corp., Armonk, NY, has a complete phaseout deadline by December 1993, and AT&T Microelectronics, Berkeley Heights, NJ, by 1994.

Companies are modifying their production processes to eliminate using CFCs as solvents and cleaners. Some of the companies are using aqueous cleaners, deionized water cleaning systems, and low- or no-flux soldering processes.

But the worry in electronics is the

Europe and Japan act swiftly to phase out CFCs

EUROPEAN and Japanese CFC makers and users have acted swiftly in response to the Montreal Protocol restricting CFC use.

The European Community, which produces 38% of the world's annual CFC supply, has a lot at stake in the conversion to substitutes. Here is what some European CFC producers are doing.

◆ ICI Chemicals & Polymers Ltd., England, is building HFC-134a production plants in Saint Gabriel, LA, and in Runcorn, Cheshire, England. ICI has invested $170 million in the two plants, which will produce a substitute refrigerant for CFC-12.

◆ Montefluos SpA, Italy's top CFC producer, is working on HFC-123 for foam blowing and HFC-134a for refrigeration. The company has built a pilot plant for both compounds and has applied for patents on its manufacturing processes.

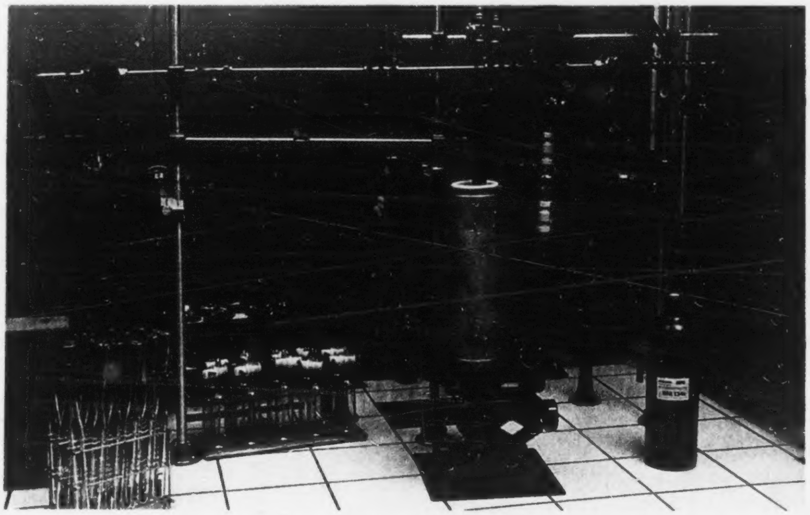
◆ Bayer AG, West Germany, has been working with refrigeration equipment manufacturers and with foam blowers to reduce the amount of CFCs by 50% in each application. Bayer also is developing chlorofluoroalkanes to be used with HCFC-22 to make a less stable product that decomposes before reaching the stratosphere.

◆ Atochem SA, a French chemical manufacturer, is testing an HFC-134a formulation for refrigeration. Atochem already has two alternate compounds on the market—HCFC-141b (a blowing agent) and HCFC-142b (a refrigerant).

◆ In Japan, the Ministry of International Trade & Industry has teamed up with Japanese chemical manufacturers in a five-year $40 million project to identify and produce alternates to CFCs. Nearly half of the CFCs consumed by the Japanese is for solvent uses in electronics manufacture.

In addition to developing new solvents, the Japanese are looking into recycling systems and alternate cleaning technologies.

One new method, developed for the cleaning of precision machinery, uses 10-μm ice crystals of pure water. Operating at temperatures of −50 C, the method first freezes impurities that are on the surface of the part and then injects the ice crystals to blast them away.



Chemicals cook in a lab at Atochem SA, Paris, during tests on CFC substitute compounds. Companies in Europe and Japan have been developing substitute compounds and alternate processes to meet the needs of the changing CFC market.

It will take 95% global compliance of the CFC ban to stabilize the chlorine levels in the stratosphere.

A Union Carbide researcher tests the resiliency of a non-CFC foam by measuring the bounce of a steel ball off of the foam.

How will the CFC phaseout affect your business?

HERE IS A list of information sources for finding out how eliminating CFCs will affect your business.

Associations

The Alliance for Responsible CFC Policy, 2011 Eye St. NW, Suite 500, Washington, DC 20006 (contact: David Stirpe).

American Electronics Assn., 1225 Eye St. NW, Suite 950, Washington, DC 20005 (John Hatch).

American Society of Heating, Refrigerating & Air Conditioning Engineers Inc., 1791 Tullie Circle NE, Atlanta, GA 30329 (Tony Giometti).

Greenpeace USA, 1436 U St. NW, Washington, DC 20009 (Peter Dykstra).

Government Agencies

Environmental Protection Agency, 401 M St. SW, Washington, DC 20460 (Stephen Anderson).

National Institute of Standards & Technology, Gaithersburg, MD 20899 (David Didion).

Manufacturers

Allied-Signal Inc., Box 1087R, Morristown, NJ 07962 (William Corcoran).

Atochem NA Inc. (formerly Pennwalt Corp.), 3 Parkway, Philadelphia, PA 19102 (Charlie Kitchen).

E.I. DuPont de Nemours & Co., 1007 Market St., Wilmington, DE 19898 (Cathy Andriadis).

Users

Cryodynamics Inc., 1101 Bristol Rd., Mountainside, NJ 07092 (Stephen Malaker).

General Motors Technical Center, 30200 Mound Rd., Warren, MI 48090-9010 (Toni Simonetti).

IBM Corp., Armonk, NY 10504 (Mack Jeffery).

York Intl. Corp., Box 1592, York, PA 17405-1592 (Bill Kopko).

cleaning of high-end products, where intricate circuit patterns and chip connections must be almost completely free of flux and residue.

"We have used a lot of [alternate] cleaning products on boards in the past, but they have been relatively simple products," says Tim Mann, who oversees IBM's program to phase out CFCs. "The more complex the boards, the more you will have to rely on using HCFC solvents."

End users are concerned too.

"The whole automotive industry is worried about CFC-113," says GM's Stofflet, who also is chairman of the Motor Vehicle Manufacturers Assn. panel on CFCs. "That compound is used to clean the fuel emission control electronic chip. Any residue that is left on it will degrade the reliability of our product."

Foam blowers, who have built their businesses on reliable and cheap CFC blowing agents, also will face a tough time converting to alternate methods. The companies are finding that several methods can be used, but they lower product quality.

Foam blowers have used CFC-11 to expand rigid polyurethane and polyisocyanurate foams and CFC-12 to expand extruded polystyrene board foam. Many companies have developed combination processes that let them reduce CFC use 30% to 50%. Eventually, compounds such as HCFCs-123 and -141b will replace CFC-11 and HCFCs-142b and -124 will replace CFC-12.

Foam blowers are working on water blowing and carbon dioxide blowing processes. Hydrofluoroalkane also is being used as a blowing agent for furniture padding, but the compound is 75 times more expensive than CFC blowing agents.

HCFC restrictions

The best alternate foam blowing agents are the HCFCs. But legislative action, such as Sen. John Chaffee's (R-RI) bill to phase out these compounds, could put severe restrictions on these agents or even eliminate their use.

Everything must go according to plan in order to meet the deadlines of the Montreal Protocol. Many chemical companies are moving ahead with plans to produce HFCs and HCFCs before their toxicity tests are complete or before laws governing their use are finalized. The chemical companies are gambling hundreds of millions of dollars in building new facilities.

Global compliance is the key to making the protocol work and to reducing damage to the ozone layer. It will take at least a 95% worldwide compliance just to stabilize the chlorine loading in the stratosphere, says NASA's Kurylo.

"We know if you stop [using CFCs] the atmosphere will cleanse itself," he says.

But that means India, China, Israel, and other countries that have not signed the protocol must participate to make it work.

"Everything is in place to [phase out CFCs]," says Manzer. "But whether everyone in the world will agree to a total phaseout of CFCs, your guess is as good as mine." **R&D**

READER RESPONSE PANEL

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High **377** Medium **379** Low **381**

What's a PhD Worth? Try $2 Million

The more education you get, the better your chances for a higher salary, our survey reveals.

*By **Robert R. Jones**, Executive Editor,* R&D Magazine

THE FINANCIAL ADVANTAGE for workers in R&D of having a PhD degree instead of just a bachelor's degree now exceeds $2 million over a 35-year career, according to the 3,800 respondents to our recent industry survey.

When all of the data are considered, the typical worker in research and development in 1990 is a 44-year-old male chemist with an MS degree, working in industry, with 18.7 years' experience and 10.3 years with his present employer. He received a 4.8% salary increase last year and now is earning just under $50,000 a year.

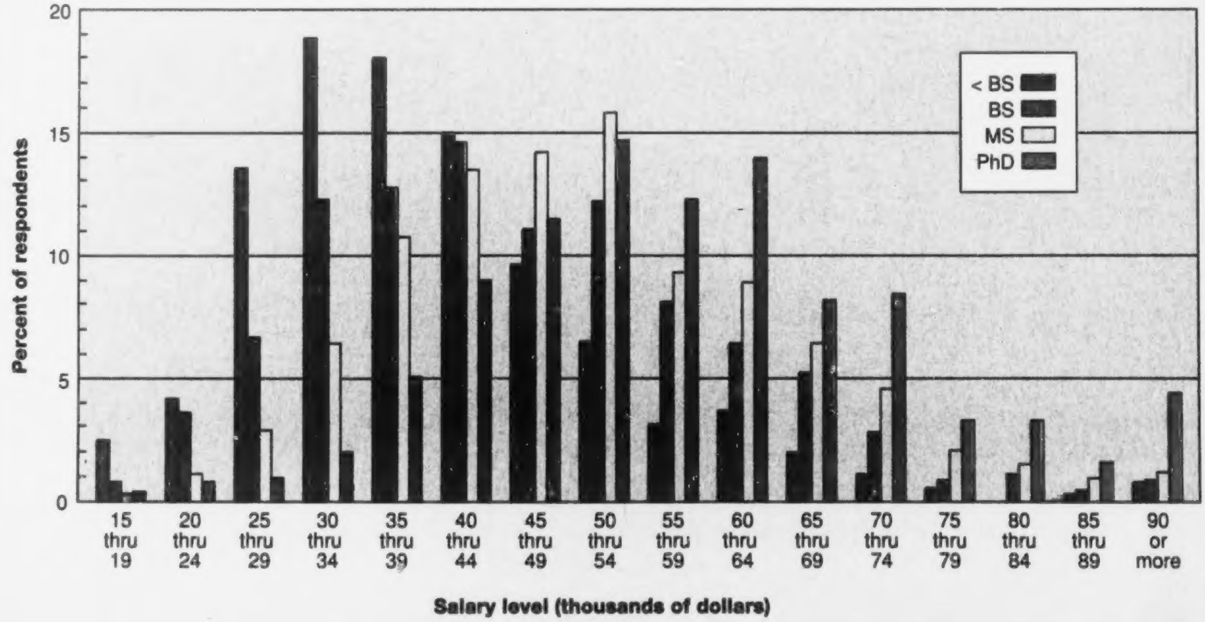
The PhD vs. BS premium in R&D has increased steadily in real value throughout the past decade. In 1980, the premium was $820,472. With an increment added to that figure every year, the premium now is almost 2.5 times that amount.

Added costs included

Today's PhD/BS premium of $2,006,552 represents an increase from 1980's figure at a rate of more than 9.3% compounded annually. That puts it well ahead of the rate of inflation in the U.S.

This premium is calculated from a formula that allows for the added cost

1990 salary by education level for all R&D workers



Pay for education is obvious as R&D workers with no degree dominate lower salary ranges, MSs the middle, and PhDs the top.

of the PhD education, for the earning years that are available to the BS individual while the PhD is being earned, and an interest rate of 8%.

While 35 years sounds like a long career, that figure is reasonable for this industry, based on respondents' reports of their years of experience. Nearly 11% report having 35 or more years' experience, and almost one in 10 of the responding PhDs is more than 60 years old, old enough to have had such a career.

Such a premium for higher education provides a strong incentive to young scientists and engineers to work for advanced degrees.

For example, spread evenly over a PhD's career, that premium amounts to an annual benefit of $57,330 over 35 years.

That premium also can be seen as returning more than $500,000 for each year spent getting a PhD, assuming a four-year doctoral program.

The biggest opportunity

The principal reason for this year's increase in the size of the PhD/BS premium is that, while the median salary for PhDs in research and development went up by 5.1% in 1990 (vs. 7.8% in 1989), the median for R&D workers with a BS degree went up only 4.2% (vs. 9.9% in 1989).

The individual who goes from high school to PhD nabs the biggest premium opportunity. The difference in median annual incomes for R&D workers with PhD degrees vs. those with no degree rose to $19,298 this year from $18,704 last year. Thus, the financial value of having a PhD degree over having no college degree at all now stands at $3.1 million over a 35-year career.

For a person who chooses to go on for a PhD after getting an MS, the 35-year return is more than $1.1 million.

There is an equal $1.1 million-plus career premium for getting a BS instead of not getting a degree at all. Respondents report that the move up from BS to MS is worth nearly $900,000 over a 35-year career. Thus, getting an MS in place of no college degree provides another opportunity for you to earn a career premium of more than $2 million.

Looking at the reward for advanced degrees in another way: Of this year's respondents who are earning $75,000 a year or more, 53.6% have earned a PhD, 24.7% have an MS, 14.5% hold a BS, and 7.2% have no college degree at all.

Among those 3,800 persons who work in R&D and responded to this survey, 9.4% are female, the same percentage of female respondents as last year.

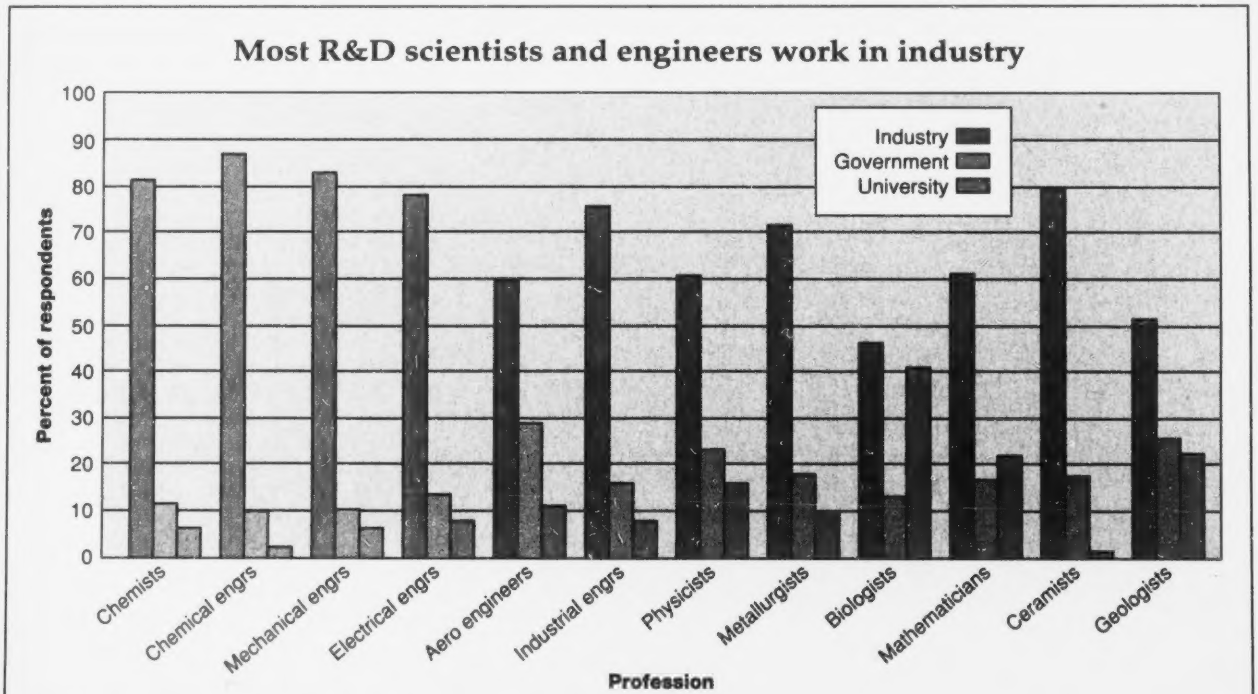
Twice as many females

The percentage of women in R&D has almost doubled over the past decade, from 4.9% in 1980 to 6.3% in 1983, to 7.2% in 1986.

However, much of the foregoing comment about salary premiums does not apply to women. Fewer women than men have earned PhD degrees and even fewer have attained 35-year careers.

Among this year's respondents, the 9.4% who are female hold only 7.7% of the PhDs; moreover, 11.4% of the men in R&D have achieved a 35-year career, while only 3.6% of the women have done so—two major reasons why men are the top money-earners in this industry.

Nonetheless, after all of the cultural factors have been allowed for, a salary difference still exists. Plainly put, there still is sexual discrimination in



R&D chem engineers and ceramists are scarce on college scene, biologists numerous; government likes aero engineers and geologists.

The financial value for an R&D worker with a PhD compared to no degree now stands at $3.1 million.

research and development.

On the positive side, however, the situation is shifting toward equality. In 1980, 9.0% of the female respondents were being paid in the upper half of the salary range. Today, 13.1% of the women are earning salaries in the upper half.

Even within the past year, the percentage of women respondents in the lower income ranges has dropped sharply. In 1989, 48.1% of the women respondents reported incomes in the bottom quarter of the salary chart.

This year, the percentage of women in that salary range is down dramatically, to 33.7%. (The corresponding figures for men were 17.6% in 1989 and 14.2% in 1990, a much less dramatic change.)

Workers in R&D with a PhD can expect to earn $12,000 more this year than those who have only a BS.

R&D salaries compared by academic degrees

Degree	Median salary 1990	Median salary 1989	Percent change	Annual difference* 1990	Annual difference* 1989	Difference change (percent)
Doctorate	$57,138	$54,351	5.1	$7,036	$6,436	+9.3
Master	50,102	47,915	4.6	5,358	4,982	+7.5
Bachelor	44,744	42,933	4.2	6,904	7,286	-5.3
<Bachelor	37,840	35,647	6.1	n/a	n/a	n/a

* Difference above next lower degree

Median salaries all R&D by workplace

	1990	1989	1980
Industry	$49,978	$48,307	$28,354
Government	48,793	45,482	29,733
University	47,500	43,181	25,685

Industry pays the top salaries in R&D today, but was No. 2 prior to 1984.

Salary increases granted in 1989 determine 1990 pay. Women outdid men in getting above-inflation raises.

Percent of R&D workers receiving salary increases by range and sex

Amount of increase	Granted in 1989 Male	Granted in 1989 Female	Granted in 1988 Male	Granted in 1988 Female
None	9.3	7.6	10.0	3.1
Less than 2%	2.6	1.4	5.3	5.6
2 through 5%	55.7	48.5	54.9	50.6
6 through 9%	24.2	30.2	21.4	31.9
10 through 13%	5.4	10.1	5.7	4.5
14% or more	3.3	2.0	2.6	4.3

Median salary by sex and workplace

	1990	1989	% change
Men in industry	$51,015	$49,434	+ 3.2
Men in government	50,061	45,802	+ 9.3
Men in universities	49,166	44,317	+ 0.9
Women in industry	40,705	36,561	+11.3
Women in government	38,654	41,249	− 6.3
Women in universities	34,167	27,499	+24.2

Women working in industrial R&D made the most salary gains last year, but still lag men in all categories. See text for comments on last two categories.

In salary increases last year, women outscored men four to three in the percentage getting increases that were larger than inflation.

The 9.4% of this year's respondents who are women captured 11.4% of the salary increases in the 6%-to-9% range and 16.1% of the increases in the 10%-to-13% range. Although they dropped to 5.8% of the increases of 14% or more, they held onto the 4:3 lead in above-inflation salary boosts.

As we reported in March, the median income for all R&D workers in 1990 is $49,632. When the median is calculated on the basis of sex and workplace (industry, government, or university), it becomes even more obvious that men earn more than women and industry pays better than government or university employers.

As it has for a number of years, the highest median for women's income, the category of women in industry, remains below the lowest-paid group of men, that of men in universities (see accompanying table).

Women making gains

However, women are making gains on men, as the 11.3% increase for women who work in industry would indicate.

There is one change of a different nature: Last year's survey stated that women in government had received salary increases that raised their median income a surprising 23.1%. This put them ahead of women in industry, but still left them lower than the lowest male median.

This large increase smacked more of sampling error than of government beneficence.

As expected, data from this year's survey confirm the suspicion that the 1989 data were flawed. The current median for women in government is down from last year's median. Nevertheless, it still represents a compounded two-year gain of 7.42%—a respectable increase and much more believable.

By the same token, the 24.2% increase that was recorded this year for women in universities calls attention to itself. While it is not large enough to change the rankings, it is an unusually high annual increment and should be looked at skeptically.

For many years, government was obviously the best place for R&D

Aeronautical engineers in R&D dominate upper age ranks, few replacements are coming on at lower end.

workers in terms of salaries. Then, beginning in 1984 with Reagan administration efforts to shift expenditures from government to industry, that changed. In recent years, R&D workers in industry have been the clear winners in the payroll sweepstakes (see accompanying table).

The division of disciplines by workplace categories is shown in the accompanying chart, which reveals that the highest percentage of any R&D discipline to work in government is aeronautical engineers at 29.0%. Only 10.1% of the chemical engineers work for government.

University R&D employs only 1.6% of the ceramists and 2.6% of the chemical engineers. Predictably, industry employs the largest portion of the chemical engineers, as it does in most disciplines.

The lowest percentage of any R&D discipline employed by industry is biologists; 40.8% of R&D biologists are employed by universities. Biologists also rank at the bottom in median salary. And the discipline with the highest percentage of women is biology, at 17.5%.

Small wonder that women biologists working in universities are at the opposite end of the income rankings from male aeronautical engineers in industry.

Where are the replacements?

Data from this survey suggest that there is cause to ask where the next generation of aero engineers may be. While 37.7% of all workers in the R&D industry are 40 years of age or younger, only 25.8% of aeronautical engineers are that young.

At the upper end of the age scale, aero engineers report that 12.9% are older than 65 years of age. This is the only R&D discipline in which more than 4% of respondents are that old.

Next in order of age are physicists, much closer to the industry average, with 33.0% being younger than 41 (mathematicians have 33.4% and industrial engineers 35.1% that young).

The age of physicists in R&D is bunched around the median age for all R&D. Although they are short of younger workers, only 1.9% of physicists are in the older-than-65 category.

In the overall R&D industry, only 3.0% of workers are older than 65. Ceramists and metallurgists are tied for having the lowest percentage of workers older than 65 at 1.6%. **R&D**

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High **389** Medium **391** Low **393**

1990 profile of the research and development industry

1. What is your annual salary?

$15,000 through $19,999	0.7%
20,000 through 24,999	2.1
25,000 through 29,999	4.6
30,000 through 34,999	8.2
35,000 through 39,999	10.4
40,000 through 44,999	12.6
45,000 through 49,999	11.9
50,000 through 54,999	13.3
55,000 through 59,999	9.3
60,000 through 64,999	9.2
65,000 through 69,999	6.1
70,000 through 74,999	4.9
75,000 through 79,999	1.9
80,000 through 84,999	1.8
85,000 through 89,999	0.9
More than 90,000	2.1

2. Your raise during the past year was

None	9.2%
Less than 2%	2.1
2 through 5%	54.9
6 through 9%	24.7
10 through 13%	5.9
14% or more	3.2

3. How long have you worked for your present employer?

Less than 1 year	4.2%
1 through 3 years	15.5
4 through 6 years	16.4
7 through 9 years	12.9
10 through 12 years	9.4
13 through 15 years	7.5
16 through 18 years	6.3
19 through 21 years	7.1
22 through 24 years	6.3
25 through 27 years	4.8
28 through 30 years	3.6
31 through 33 years	3.2
34 through 36 years	1.3
More than 36 years	1.5

4. What is your age?

Under 26 years	1.9%
26 through 30 years	8.0
31 through 35 years	14.3
36 through 40 years	13.5
41 through 45 years	14.1
46 through 50 years	15.2
51 through 55 years	12.9
56 through 60 years	11.3
61 through 65 years	5.8
Older than 65 years	3.0

5. How many years of experience do you have?

Less than one year	0.7%
1 through 5 years	9.1
6 through 10 years	14.7
11 through 15 years	15.5
16 through 20 years	13.7
21 through 25 years	14.0
26 through 30 years	12.8
31 through 35 years	11.0
36 through 40 years	6.0
More than 40 years	2.5

6. What is the highest degree you hold?

Less than bachelor	9.4%
Bachelor	34.0
Master	24.9
Doctorate	31.7

7. What is your profession?

Chemist	33.9%
Chemical engineer	7.1
Mechanical engineer	13.2
Electrical engineer	10.2
Aeronautical engineer	1.6
Industrial engineer	1.0
Physicist	8.1
Metallurgist	5.1
Biologist	5.4
Mathematician	0.5
Ceramist	1.7
Geologist	0.8
Other	11.4

8. Do you work in

Industry	75.4%
Government	13.9
University	10.7

9. Are you

Male	90.6%
Female	9.4

Applications Explode For Lasers and Electro-Optics

R D *Perspectives*

More power, faster pulses, and new materials are opening doors in lithography, diagnostics, and spectroscopy.

*By **Tim Studt**, Associate Editor,* R&D Magazine

THIS MONTH marks the 30th anniversary of the first laser. On May 15, 1960, Theodore Maiman, a researcher at Hughes Aircraft Co., used a solid ruby crystal to produce the first coherent laser light.

Today, researchers are working without letup to develop new laser systems and expand their applications. They are developing lasers to measure the adhesion of thermal tile to space shuttles, make 3-D models from CAD designs in a matter of minutes, and sculpt human corneas eliminating the need for glasses or contact lenses.

Not even counting the laser R&D being done in fusion and the Strategic Defense Initiative programs, most national laboratories and universities have several ongoing research programs that involve lasers. Most of this work is directed at industrial, medical, and analytical applications.

Using big lasers

Bigger and faster. That's what industrial laser research is emphasizing.

Most heavy industrial laser applications still rely on CO_2 lasers for metal cutting, welding, and ablation.

Conversely, most CO_2 lasers are used for industrial applications. More than 75% of the 2,100 CO_2 lasers sold in 1989 were rated at more than 500 W and were designed for materials-processing says Dennis Fortino, president of the Rofin-Sinar Div. of Siemens Components Inc., Santa Clara, CA.

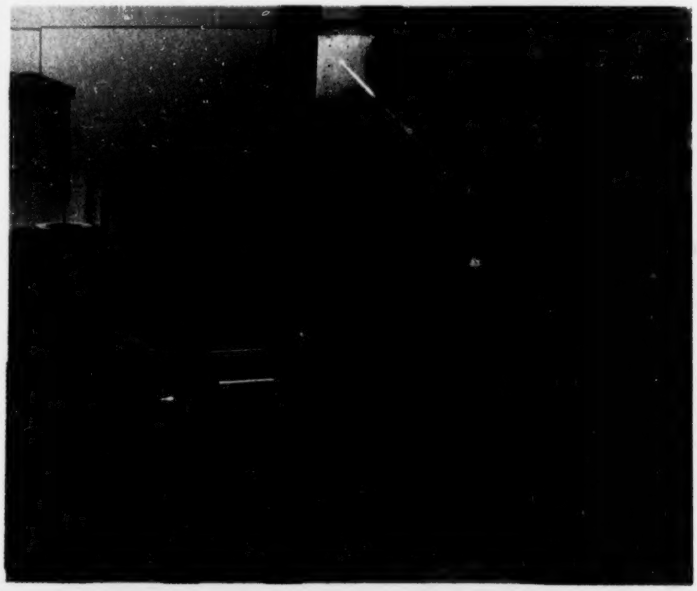
CO_2 laser research has concentrated on increasing power levels, improving power supply efficiencies, and increasing pulsing capabilities.

Power supply research has reduced the footprint of CO_2 systems by half and costs by a third during the past five years. Additional advancements are being realized as solid-state switched-mode and RF sources replace traditional power supplies.

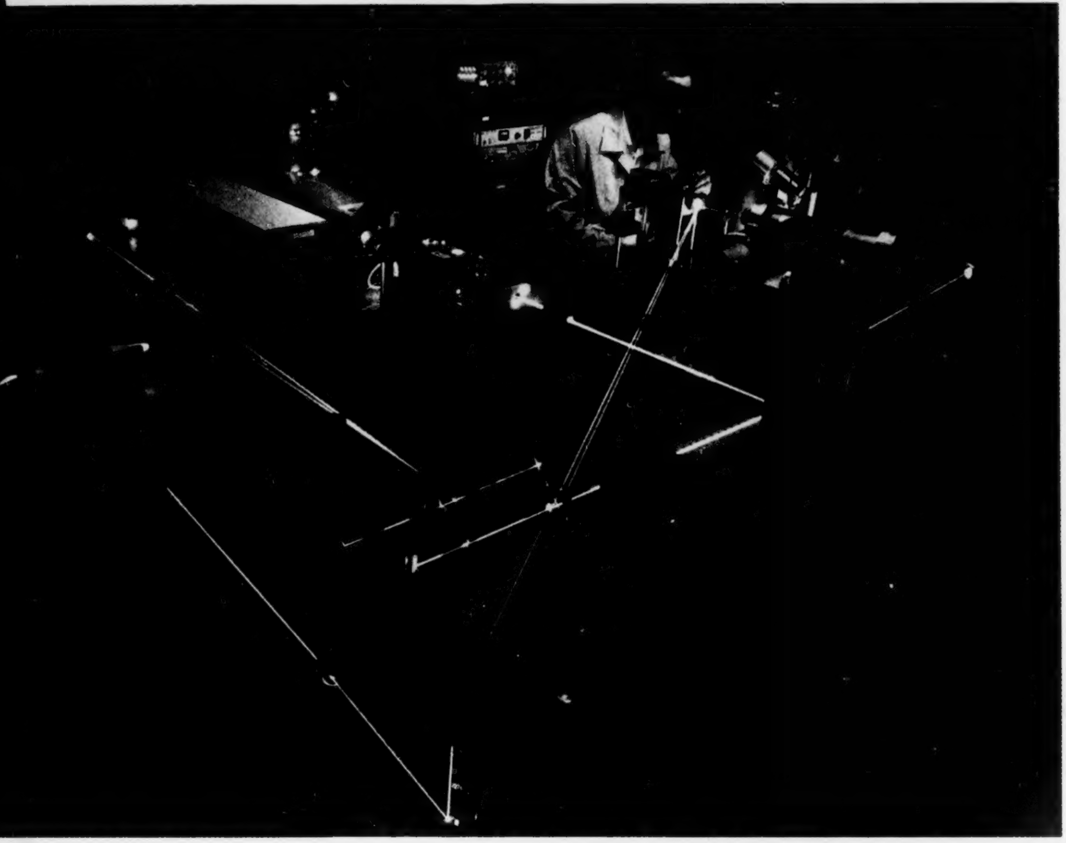
Using microwaves to excite lasers has been discussed for some time, but microwaves do not readily penetrate the discharge plasma generated in a laser. Recently, researchers at Mitsubishi Central Research Labs, Hyogo, Japan, developed a CO_2 laser with a discharge chamber that allows microwave excitation. These lasers are more controllable than traditionally excited CO_2 lasers and can be used to process ceramics and other dielectric materials with less thermal damage.

Additional cavity improvements are being developed. "Current systems are only at 50% of the thermodynamic design limits. We foresee at least two more generations of CO_2 lasers," says Fortino.

For heavy industrial use,



A Nd:YAG laser at Idaho National Engineering Lab is focused on space shuttle thermal tiles to simulate re-entry conditions. A HeNe laser measures the resultant vibrations.



***A researcher** at Battelle's Pacific Northwest Lab combines two dye lasers with a CO_2 laser to create a high sensitivity mass spectrometer that can measure radon exposure in humans.*

even higher power levels than the 10- to 25-kW systems now available are desired. One application for high-powered systems is spot welding of automotive body sections.

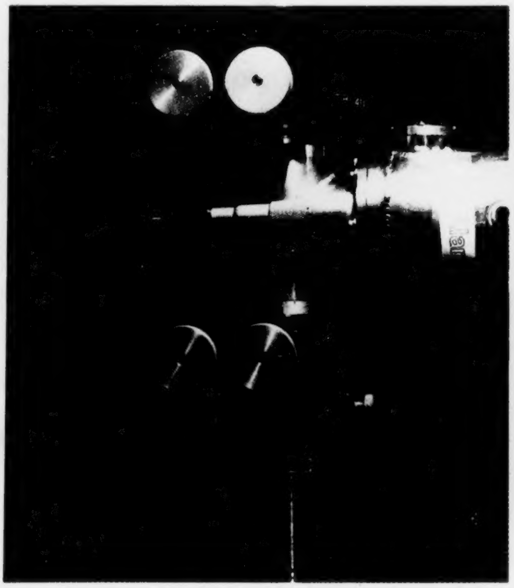
A typical car has about 9,000 spot welds, with 50% of them redundant. Using an automated laser process could eliminate 80 lb of spot-weld flange material per car.

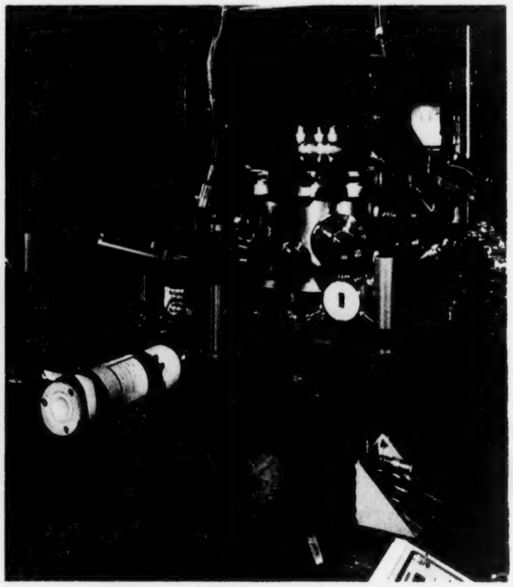
Most domestic automotive firms have laser technology groups working in this area. A few General Motors production cars already have internal body subassemblies welded with CO_2 lasers.

Because of their inherent reliability and low cost, most of the industrial laser research is devoted to refining CO_2 lasers.

Excimer and solid-state lasers also are being increasingly used in specific industrial application areas, such as low-power welding, processing of organic materials, and semiconductor lithography.

Solid-state Nd:YAG lasers are inherently easier to operate than CO_2 lasers. "They also have shorter wavelengths, which allow them to be used with fiber optics, which CO_2 la-



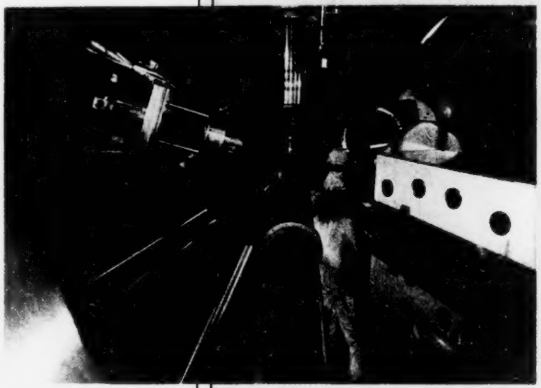


***Bright blue** fluorescence highlights an excimer laser beam (near left) used to produce low-cost tunable XUV radiation at Sandia National Laboratories.*

A solid-state blue laser (far left) was developed at Los Alamos by simultaneously pumping a Tm:YLF crystal with red and near-IR lasers.

'A big area for industrial laser research is stereolithography,' says Stephen Anderson.

Laser fusion in limbo



A researcher checks out the laser diagnostics inside Livermore National Laboratory's main Nova fusion chamber.

LASER FUSION research is on hold until the Dept. of Energy (DOE) completes a full review of U.S. fusion research policy.

After more than a year of discussions, the DOE recently assembled a Fusion Policy Advisory Committee. In September, the committee is expected to recommend how the two main fusion research programs—laser-based inertial confinement fusion (ICF) and magnetic confinement fusion—will be structured and supported.

Most program improvements are only in the proposal stage, including:

- Upgrading Livermore's 100-J Nd:glass Nova laser system to a 1-MJ high-gain system
- Upgrading the Nd:glass Omega system at Univ. of Rochester, NY, to 35 kJ
- Continuing development of the KrF excimer lasers in the Aurora ICF facility at Los Alamos (NM) National Laboratory.

"These upgrades have been endorsed by the Academy of Sciences, but the money is not in the budget. So all of them are sort of hanging at the moment," says Stephen Dean, president of Fusion Power Associates, a Gaithersburg, MD-based market-research firm.

sers cannot do," says Rofin-Sinar's Fortino. However, Nd:YAG lasers cost more and have lower power ratings than CO_2 lasers.

A few 500-W Nd:YAG lasers now are available with 1-kW versions being developed. While research will bring the current costs down, they will remain higher than CO_2 systems for some time.

Industrial firms in Japan and Europe are pursuing research in kilowatt-scale excimer lasers. They are more interested in developing high-energy lasers for industrial applications than U.S. industrial firms.

However, niche industrial applications still are being developed in the U.S., such as the development of new cutting methods for materials.

For example, Palaniappa Molian, a researcher at Iowa State Univ., Ames, is developing laser systems to cut nickel-chromium alloys, which are damaged by traditional machining. "If we use an acetylene-gas jet with a laser, we can obtain a temperature hot enough to cut and weld these materials," says Molian.

Another niche area is laser enrichment of nuclear fuels. The U.S. share of the world market for nuclear-fuel materials dropped from 100% in the mid-1970s to 50% today. To regain some of this market, scientists at Lawrence Livermore (CA) National Laboratory developed a low-cost uranium atomic-vapor isotope separation process.

The project, which uses copper and dye lasers to separate different uranium isotopes in a purification process, has been under development for several years. Performance demonstrations are scheduled for 1991. The National Academy of Sciences is studying alternate uses of this system, such as purification of industrial materials.

"A big area for industrial laser research is in stereolithography," says Stephen Anderson, market development manager for Spectra-Physics Inc., Mountain View, CA.

In stereolithography, a CAD program drives a medium-power laser, such as HeCd or argon ion, to trace the contours of a CAD-created design on uncured acrylic-polymer resin. This cures the resin in the shape of the part in minutes, compared with the hours or days that previous clay or wood methods required.

The parts made in a stereolithography system can be used as master models for mold-making processes, visualization samples for researchers, and checks for fit and function in assemblies.

Several hundred systems from such companies as 3-D Systems Inc. (Valencia, CA), Quadrax Corp. (Portsmouth, RI), and DuPont Inc. (Wilmington, DE) are already used in the U.S., while Sony (Tokyo) and Mitsubishi (Tokyo) are making similar systems in Japan.

Sony's system makes the largest parts, which can be up to 100 cm on a side. Software interfaces also are available for

Understanding the jargon

boule: A synthetically grown single crystal that is used to make solid-state lasers.
FEL: Acronym for free electron laser, a laser that uses a high energy electron beam to amplify the power in a laser pulse.
laser: Acronym for light amplification by stimulated emission of radiation.
modelock: Synchronizing a laser's harmonic modes of oscillation to create a short pulse.
pump: To use an external photon source to excite an atom from one energy state to a higher energy state.
Q-switch: Electronically build up ions in a lasing medium and then switch to a higher value just before an instability occurs, thus creating a high-power pulse.
YAG: Acronym for yttrium-aluminum-garnet, a synthetic crystal capable of lasing in the infrared. Similar acronyms include YLF (yttrium-lithium-fluoride) and GFG (gallium-fluoride-garnet).

these systems from most CAD-software companies.

A variation on this theme is selective laser sintering as shown in the accompanying figure. Developed by researchers at Univ. of Texas, Austin, and recently licensed to Austin-based DTM Corp., laser sintering uses a CAD-driven CO_2 laser to fuse powdered polymer particles into a part. "The wider range of materials that can be used with laser sintering is an advantage over other photopolymer systems," says Paul McClure, DTM's president.

Operating with lasers

"More than 90% of all ophthalmologists own or have access to lasers for performing such treatments as retinal coagulation, retinal reattachment, glaucoma alleviation, and the clearing of secondary cataracts. Ophthalmologists' love affair with the laser continues unabated," says Irving J. Arons, a senior consultant specializing in ophthalmic and medical lasers at Arthur D. Little Inc., Cambridge, MA.

Recent research in this area includes development of corneal sculpting techniques that can eliminate the need for eyeglasses or contacts in most nearsighted, farsighted, or astigmatic individuals.

In this procedure, an ArF excimer laser is used to reshape the cornea. Cellular matter is removed from the cornea by breaking molecular bonds one cell at a time with the laser. This surgery does not damage the surrounding tissue, takes less than a minute, and heals within two days.

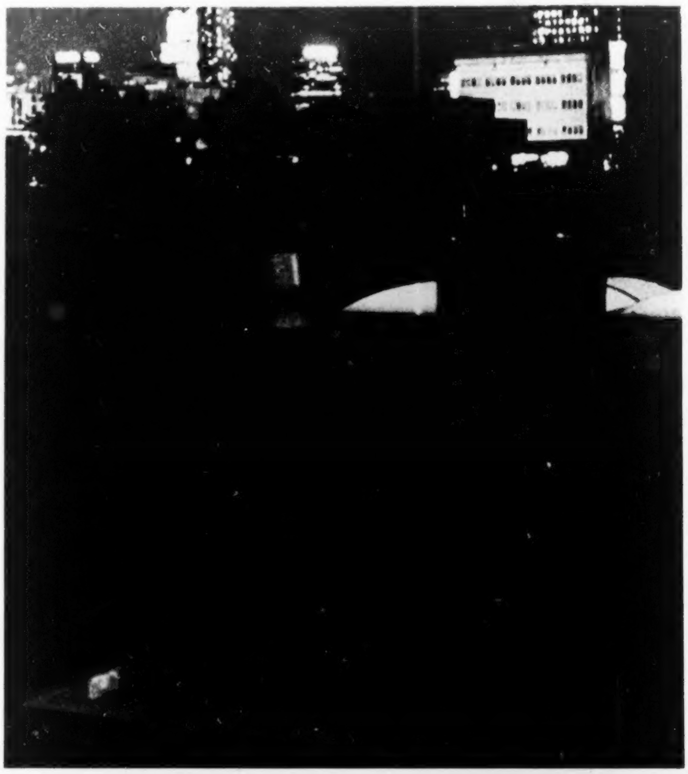
Several companies, including IBM, are battling for patent rights to this technology.

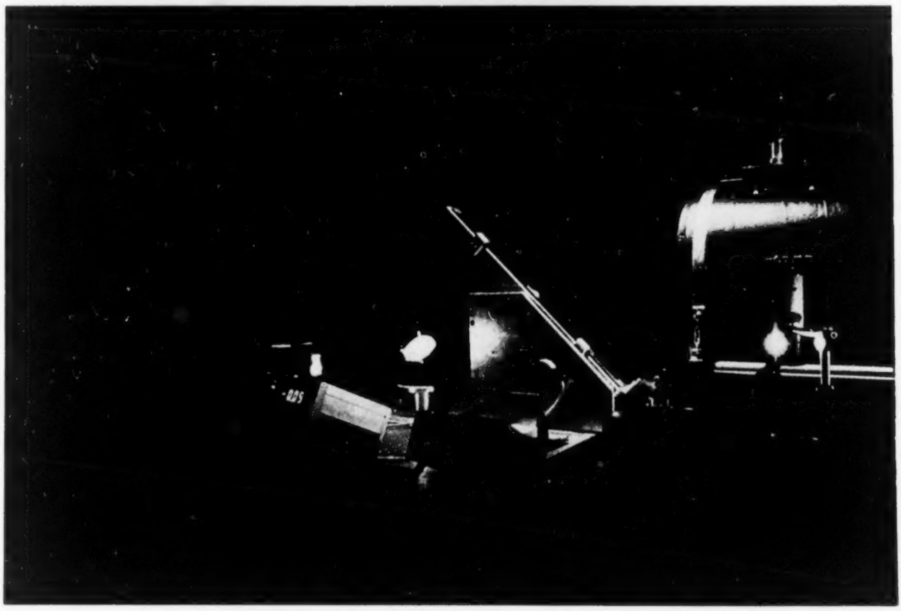
Other laser companies are developing similar processes that use diode-pumped Er:YAG, Ho:YAG, and YLF (yttrium-lithium-fluoride) lasers to vaporize subsurface corneal cells that then collapse and heal, thus changing the shape of the cornea.

Other medical applications of excimer lasers include angioplasty, arthroscopy, and dentistry. Research in laser angioplasty—the ablative removal of plaque in blocked coronary arteries—has been hindered recently by professional concerns over the effectiveness of any type of angioplasty, mechanical or laser.

In arthroscopy, CO_2, excimer, Nd:YAG, and Ho:YAG lasers are used in complementary procedures to remove both soft and dense tissues.

"However, the absorption coefficient for water at the 2,100-nm wavelength of newer





A Georgia Tech researcher (below) sends a laser beam into the air above Atlanta (left). An analysis of the beam's returned scatter shows wind velocities, air turbulence, dust, smoke, and CO_2 content.

> **The most significant recent event in spectroscopy is the introduction of titanium-sapphire lasers.**

Ho:YAG lasers is 20 times better than for the traditional Nd:YAG wavelength of 1,060 nm," says Ahmad Abu-Shumays, an engineering program manager for Coherent Medical Group, Palo Alto, CA. This makes the Ho:YAG more effective at cutting through cartilaginous tissue.

In dentistry, an excimer laser can be used to "drill" holes in tooth enamel, while a pulsed-Nd:YAG laser vaporizes any tooth decay.

The tunability of pulsed-alexandrite (chromium-doped chrysoberyl) lasers allows them to be used to develop photodynamic-therapy (PDT) methods to treat cancer. PDT is the in vitro killing of cancer cells by high-energy pulses of specific wavelength laser light without harming surrounding healthy tissues.

The U.S. has the lead in laser-based medical technology over slightly smaller efforts in Japan and Europe.

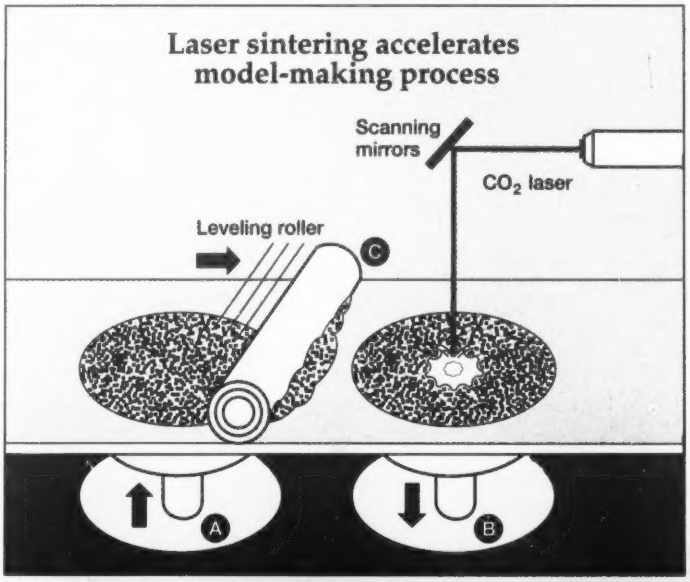
The application of lasers to analytical measurements varies from well-known laser spectroscopy and interferometry to lesser-known methods, such as dosimetry, adhesive-bond measurements, and thermal diffusivity.

Spectroscopy follows range finding and interferometry as the newest analytical application for lasers. The most recent event in laser spectroscopy has been the introduction of titanium-sapphire (Ti:sapphire) lasers that complement the performance of traditional dye lasers.

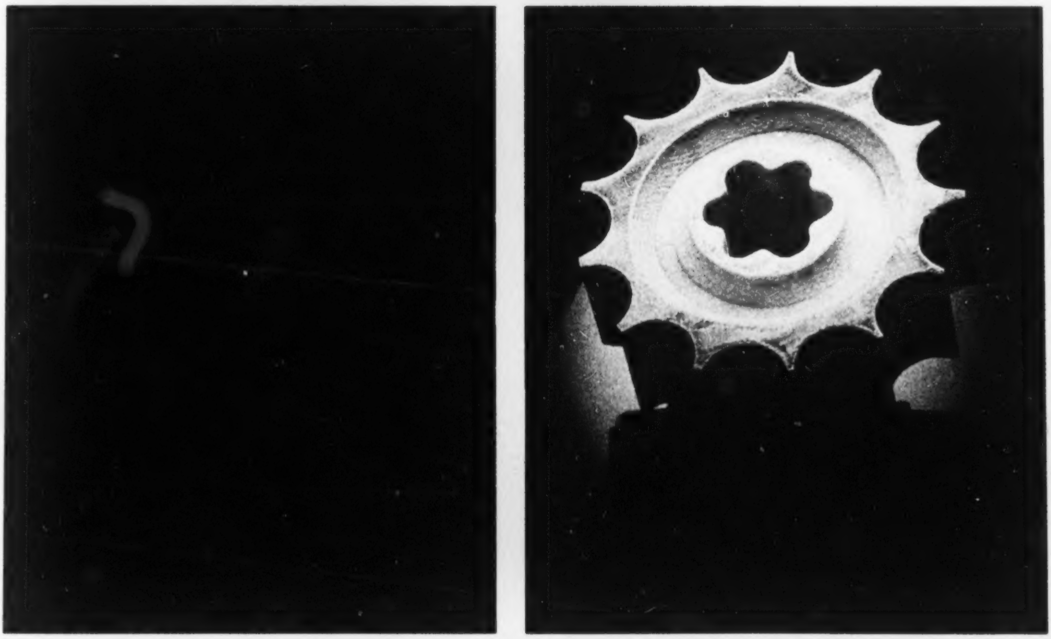
The power of Ti:sapphire lasers is significantly higher than dye lasers with fewer shortcomings, primarily the elimination of carcinogenic dyes.

New lasers are being developed for laser spectroscopy, such as the cobalt-doped MgF_2 laser developed by Peter Moulton at Massachusetts Institute of Technology's Lincoln Laboratory, Cambridge, and the chromium-doped $LiCaAlF_6$ laser at Livermore National Laboratory. The tunability of these and other solid-state lasers is the driving force in laser spectroscopy.

Combinations of existing systems also have proven to be useful for research applications.


Laser sintering accelerates model-making process

A laser sintering system has two cylinders, one pushing powder up (A) and one lowering to receive powder (B) from a leveling roller (C). A CO_2 laser scans and fuses the powder to a desired cross section.



It took only a few hours to generate this gear design (near right) on a CAD system and use the computer output to drive a laser sintering system to make a plastic part (far right).

'Ophthalmologists' love affair with the laser continues unabated,' says Irving Arons.

For example, researchers at Oak Ridge (TN) National Laboratory combined resonance-ion mass spectroscopy (RIS) with a laser-induced fluorescence-spectra system to design an instrument that monitors the growth of high-temperature superconductor thin films.

Combining laser systems also worked for Battelle's Pacific Northwest Laboratories, Richland, WA. At Battelle, researchers combined two dye lasers with a CO_2 laser to develop a double resonance ionization mass spectrometer (see accompanying figure). This instrument is hundreds of times more sensitive than conventional techniques in the measurement of trace elements, such as lead-210 and strontium-90.

Laser acoustics is another analytical technique being developed. At Georgia Institute of Technology, Atlanta, researchers Yves Berthelot and Jacek Jarzynski have developed a laser probe that nondestructively measures sound in submerged structures. "We're trying to understand the physics of how sound waves are radiated," says Berthelot.

Their system uses laser-Doppler interferometry methods. A beamsplitter divides a laser beam into two beams, which are fed into two fiber optic cables that transmit the beam to the experiment. There, the two laser paths are crossed at the vibration point under study. The light beams scatter off the structure, and the vibrations modulate the light. Berthelot and Jarzynski then analyze the resultant data to obtain information on the vibrations.

Researchers at Idaho National Engineering Laboratory, Idaho Falls, use similar laser acoustic methods to measure the micromechanical resonance of materials. The initial application involves testing the adhesive bond integrity of space shuttle thermal tiles (see accompanying figure).

A laser-based dosimetry—radiation detection—measurement system has been developed by researchers at National Institute of Standards & Technology, Gaithersburg, MD. The system uses a HeNe laser light source to monitor processes such as polymer curing, sterilization of medical equipment, and semiconductor hardening.

Hot optical research

Nonlinear optics, self-scanning detector arrays, and optical fibers are hot areas in electro-optics research. Nonlinear optics are used to frequency double dye and solid-state lasers for spectroscopic applications.

Spectra-Physics has developed a beta-barium borate crystal that efficiently doubles a laser frequency below 200 nm for high-energy pulsed lasers. "However, the material is hard to obtain—it comes from China—and we are [codeveloping] a similar material, lithium borate," says Sicco Westra, manager of solid-state laser systems at Spectra-Physics, Mountain View, CA.

Researchers at Epitaxx Inc., Princeton, NJ, have developed an InGaAs multiplexed linear photodiode array that performs the same function as traditional multiplexed silicon devices, but in the near-IR as opposed to the UV-visible spectrum. This detector has applications in near-IR spectroscopy, where it performs better than the conventional germanium detectors.

Researchers at AT&T Bell Laboratories, Murray Hill, NJ, have developed an erbium-doped optical amplifier fiber for use as a fiber-optic communications cable. Its 1,550-nm signal is pumped with a 1,480-nm semiconductor laser. This amplifies the optical signal 100

Will politics shoot down SDI lasers?

POLITICS WILL determine the future role of high-energy laser research in the SDI (Strategic Defense Initiative) program. The Bush administration's proposed FY91 budget for the directed energy weapons (DEW) category of SDI is $810 million, up from $703 million for FY90.

If SDI survives FY91 budget battles, high-energy laser programs still will have to compete against internal SDI programs, such as development of neutral particle beams and kinetic energy weapons (KEW). Most Congressional representatives favor DEW weapons, while the administration favors KEW.

Of the $810 million, the administration proposes spending $211 million for chemical laser research and $130 million for free electron laser (FEL) research.

Last fall, Boeing, Seattle, and Los Alamos (NM) National Lab won an SDI contract to develop an FEL that's expected to be the world's largest, when it's completed.

As part of DEW system research, a low-power atmospheric compensation and relay mirror experiment satellite was launched in January 1990. The satellites will be used during the next several months to develop data on long-distance optical paths of lasers and interaction of laser beams with the atmosphere.

Boeing engineer Dick Lowrey uses a magnetic probe to check the magnetic field around the company's free electron laser system.

AT&T developed a laser-pumped fiber-optic cable that amplifies optical signals 100 times.

times at a pump power of less than 4 mW. This in-line amplifier eliminates the signal-conversion and reconversion process needed in traditional systems.

Making blue lasers

Developing a solid-state blue laser has been a goal of researchers for some time because of its potential use in communications, therapeutics, chemical analysis, and consumer electronics.

Researchers at Livermore National Laboratory and Los Alamos (NM) National Laboratory both have developed blue lasers, but with different processes.

To make his blue laser work, Livermore researcher Richard Solarz made Nd operate in a ground-state depletion mode in a Y_2SiO_5 crystal grown at AT&T Bell Labs. "The magic about this is that when the Nd lases back to the ground state, simple frequency doubling takes it to 455 nm (blue wavelength)," says Solarz.

To operate his blue laser, Los Alamos researcher Dinh Nguyen uses an "upconversion" process in which thulium ions become excited by absorbing low-energy IR photons from a semiconductor laser. The electrons jump to a high-energy level from which they emit a high-energy blue photon (see accompanying figure).

Upconversion generates the same visible light power as gas lasers, but with efficiencies almost 100 times greater than with conventional gas lasers. One potential application is in the replacement of hazardous wet chemistry techniques. "They can be used in a number of defense and R&D areas—anywhere other visible gas lasers are being used," says Allen Hartford, head of the chemical and laser sciences division at Los Alamos. **R&D**

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Institute of Electrical & Electronic Engineers, Laser & Electro-optics Society, 345 East 47th St., New York, NY 10017; 212/705-7900

Laser & Electro-Optics Manufacturers Assn., 72 Mars St., San Francisco, CA 94114; 415/621-5776

Laser Institute of America, 12424 Research Pkwy, Suite 130, Orlando, FL 32826; 800/345-2737

National Laser Users Facility, Univ. of Rochester, 250 East River Rd., Rochester, NY 14623; 716/275-5105

Scientific Events

Conference on Lasers & Electro-Optics, Optical Society of America, 1816 Jefferson Place NW, Washington, DC 20036; 202/223-0920

Lasers and electro-optics business highlights

U.S. laser patents drop

U.S. Dominance in laser technology has eroded during the past several years. Last year, U.S. inventors received 714 laser patents, 21 fewer than in 1987. During the same period, foreign-based researchers increased their total number of patents from 550 to 663.

The biggest holder of U.S. laser patents is the Federal government. In 1988, the Dept. of Defense received 43 laser patents, the Dept. of Energy received 24, and NASA was awarded 3 patents.

For more information: MicroPatent 800/648-6787.

A global laser industry

Patent holders	1989	1988
U.S. government	58	70
Hitachi	34	36
Toshiba	32	26
Sharp	27	39
Mitsubishi	27	37
Hughes Aircraft	27	22
Siemens	25	27
General Electric	25	21
Spectra Physics	20	18
Minolta	20	5
Canon	20	14

Source: MicroPatent

U.S. laser market grows

Materials processing, R&D, and medical applications account for more than 75% of the $314 million U.S. laser market, according to a recent study by Frost & Sullivan, a New York-based market research firm. The U.S. accounts for about half the total world market in lasers.

U.S. sales are expected to reach $412 million by 1994. Ion, CO_2, and solid-state lasers are the strongest growth areas with combined U.S. sales of $195 million in 1989 and forecasted annual sales of $260 million by 1994.

Next: Corneal sculpting

More than half of the ophthalmologists in a recent survey said they would charge between $1,000 and $1,500 per eye to perform laser-based corneal sculpting, according to Arthur D. Little, a consulting firm based in Cambridge, MA.

The laser sculpting procedures use an ArF excimer laser to remove corneal material. The reshaping procedure takes less than a minute and can eliminate the need to wear glasses or contacts.

"Five years after FDA marketing approval, there will be 2 million sculpting procedures performed annually," says Irving J. Arons, a senior consultant in medical laser technologies for Arthur D. Little.

R D

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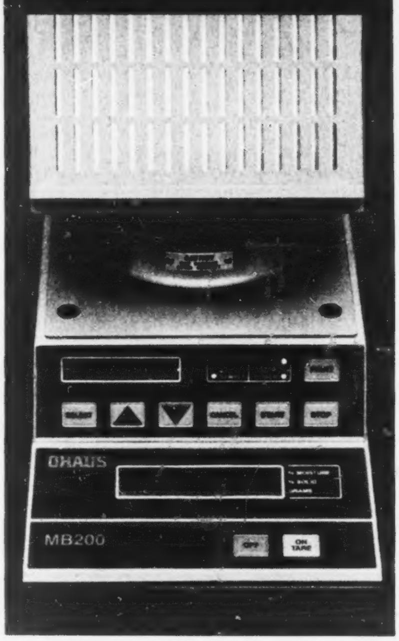

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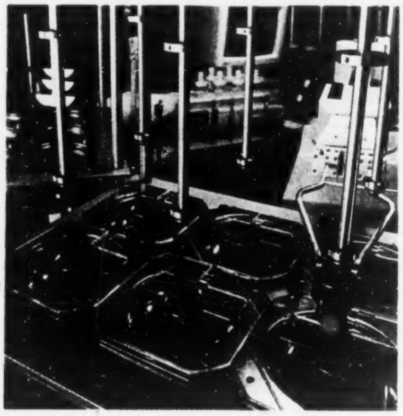

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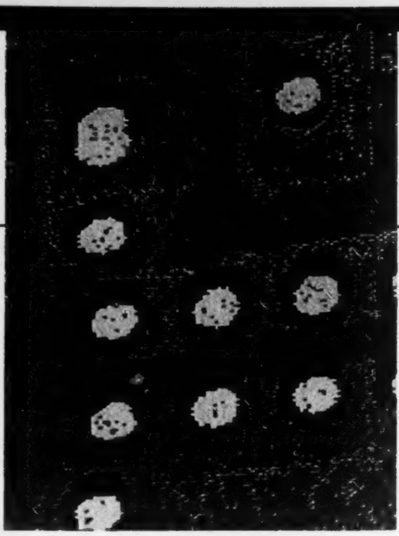

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BUSINESS

Japan and Germany cut into U.S. R&D lead

THE GOOD NEWS is that the U.S. still leads the world in "big" R&D categories, such as total money spent, total number of researchers, and volume of high-tech exports, according to a recent National Science Foundation study.

The bad news is that while these totals look great, their rates of change have leveled off or decreased in recent years. The study, *Science & Engineering Indicators–1989,* says that at the same time foreign countries increased their R&D efforts.

The number of Japanese researchers per 10,000 workers in the labor force, for example, exceeds that in the U.S. for the first time. Also, R&D expenditures as a percentage of GNP in Japan and Germany exceeded U.S. expenditures every year since 1984, and each year the difference increases.

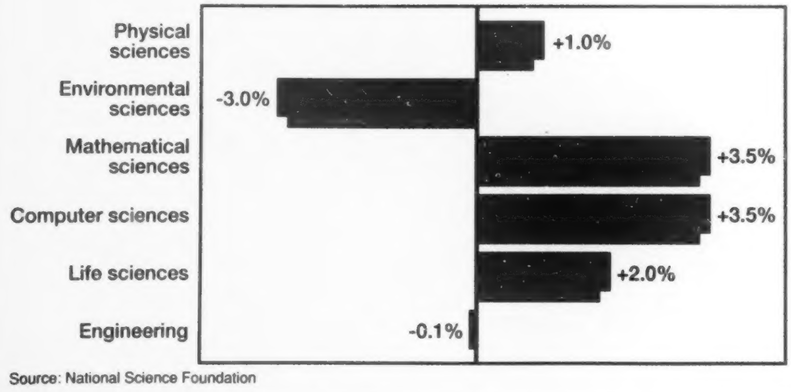
The study reveals that, from 1985 to 1989, the U.S. had smaller growth rates in R&D funding and science and engineering personnel than in the 1975 to 1985 period. The U.S. also had a smaller global share of high-tech trade goods, little improvement in school math and science performance, and smaller increases in science and engineering enrollments.

One area that continues to show strong U.S. growth is basic research performed in universities. Basic research in the U.S. has grown 3% annually (in constant dollars) during the past three years, while the development and applied research components of R&D have grown only 1%.

For a copy: NSF stock #038-000-00583-9, price $26; 202/357-7861. ☐

Enrollments in graduate science and engineering are slowing

(Percent change, 1987 to 1988)



Source: National Science Foundation

***Although some enrollment** categories increased and others decreased, total enrollment went up 1% from 1987 to 1988—half the rate of increase from 1980 to 1987.*

DuPont to sell thermal analysis unit

TWO DUPONT instrument businesses, the process instrument group and the air and noise monitoring instrument group, have been sold to New York-based Ametek Inc. as part of a restructuring move by DuPont's Polymer Products Dept., Wilmington, DE.

The restructuring is expected to achieve cost reductions of $100 million in 1990.

DuPont's thermal analyzer business also is being sold to a newly formed company led by management and employees of the existing business. Both sales are expected to be finalized by early July.

DuPont has been selling thermal analyzers since the 1960s and is one of the leaders in worldwide sales.

Reports of DuPont's intent to eliminate up to five polymer resins from its current product line as part of this restructuring are "highly speculative," says DuPont spokesman Tom Barry.

The restructuring also will eliminate 900 employees—9% of the polymer department's employment. About 270 of these jobs are salaried positions based in the Wilmington area. ☐

Molecular spectroscopy to grow 10.7% annually

MOLECULAR spectroscopy instrument sales are forecast to grow nearly 10.7% annually from current annual sales of $1.2 billion to $1.8 billion in 1993, according to Strategic Directions Intl., a Los Angeles-based market research firm.

These instruments include fluorescence, visible, and IR spectrophotometers and FT-NMR, mass spectrometers, and Raman spectrometers. Near-IR spectrophotometers are expected to increase the fastest in this group, at an 18% annual rate.

Most instruments are used in process and product analytical support.

State tech managers must do their homework

KNOWING THE STRENGTHS and weaknesses of the local economy helps in the success of a state technology program, says David Osborne in his recently completed *State Technology Programs–A Preliminary Analysis of Lessons Learned.*

With this knowledge, a state can establish and update strategic plans that determine how to proceed, says Osborne. Michigan analyzed its manufacturing sector with a strategic audit, then followed up with detailed analyses of the auto industry.

"Few state [programs] are working with industrial groups to improve their competitive edge," says Osborne, an associate at the Council of

R&D

CIRCULATION

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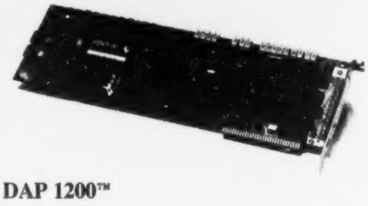

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Research & Development

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DuPont's Edgar Woolard leads environment crusade

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Program instruments on time and under budget

Lau
UNIROYAL

Chemist Lauren Rice is one of many researchers who say they made the right career choice

INTERNATIONAL MAGAZINE OF RESEARCH AND DEVELOPMENT

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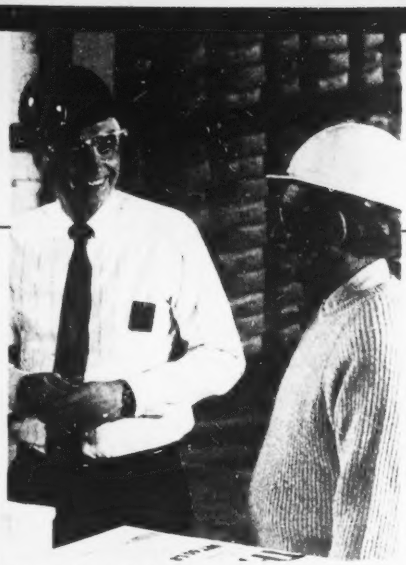

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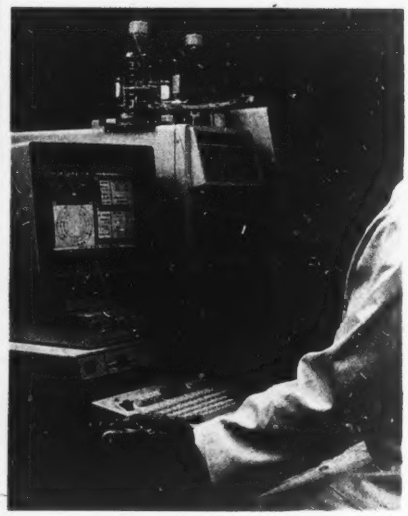

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Chemist Lauren Rice says if she had to do it all over again she would choose the same profession, and so would nearly three-fourths of the more than 4,000 respondents to R&D Magazine's first Career Satisfaction Survey. See story on page 40. Photograph by Robert Keeling.

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Three agencies agree on emerging technologies

JAPAN'S MINISTRY of International Trade and Industry (MITI) and the U.S. Departments of Commerce (DOC) and Defense (DOD) all agree that development of new materials, advanced semiconductor devices, and high-performance computing systems are the lead items to long-term economic and defense superiority.

In its *Emerging Technologies—A Survey of Technical and Economic Opportunities,* the DOC forecasts $325 billion in U.S. sales and $700 billion in combined worldwide sales for these three technologies by the year 2000. Based on a survey of government and industrial experts, the DOC concludes that U.S. research efforts in these categories lag similar efforts by Japan.

Although the main purpose of DOD's recent *Critical Technologies Plan* is to outline a program that will enhance the performance of weapons systems, a strengthening of the U.S. industrial base is added to this year's technology selection criteria. Both the DOC and DOD reports cite their interdependence on dual-use technologies and the resultant benefits in economic and defense areas.

DOD also recognizes the importance that U.S. Dept. of Energy provides through its national laboratory system.

U.S. Report Card

U.S. vs. Japan	A	B	C	D
Advanced materials				✓
Biotechnology				✓
Artificial intelligence		✓		
Optoelectronics			✓	
Superconductors				✓
U.S. vs. Europe				
Digital imaging				✓
Medical devices			✓	
Advanced semiconductors		✓		
Sensors		✓		
High-performance computing	✓			

A = Gaining C = Losing
B = Holding D = Losing badly

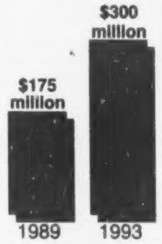
Source: U.S. Dept. of Commerce

DOC, DOD, and MITI list other critical technologies, but at a lower interest level. DOC lists nine additional emerging technologies, including biotechnology, high-density data storage, and flexible computer-integrated manufacturing. DOD lists 17 additional technologies, including machine intelligence and robotics, photonics, and superconductivity.

MITI lists aerospace, energy and quantum engineering, and biotechnology as other emerging technologies, but the working group at MITI has low expectations about their short-term usefulness.

For copies of the reports: DOD's *Critical Technologies Plan,* 202/695-4131; DOC's *Emerging Technologies,* 202/377-8090. —*Tim Studt*

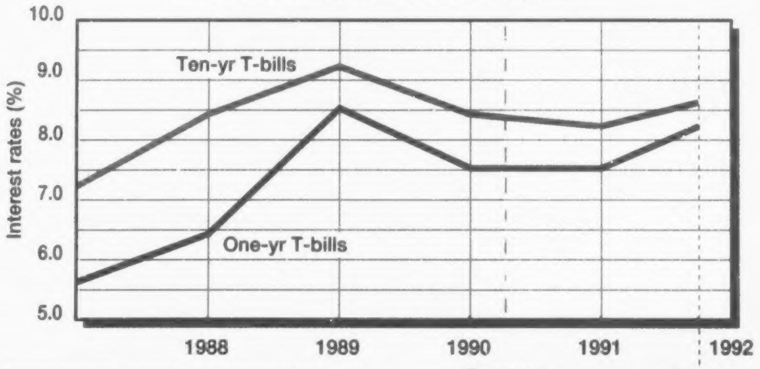
Thermal analysis market to grow 15% annually



THE worldwide market for thermal analysis instrument sales will exceed $300 million in 1993, according to Strategic Directions Intl., a Los Angeles-based management consulting firm.

The most popular thermal analysis technique is differential-scanning calorimetry (DSC). The simultaneous use of DSC and dielectric thermal analysis is the fastest growing market.

Interest rates forecasted to climb



Source: Federal Reserve Board, Cahners Economics

Cahners Economics forecasts that easing inflation will hold interest rates steady through the end of 1990, and economic growth will drive the rates up in 1991.

Steady interest rates helps high-tech growth

IN SPITE OF their recent rise, interest rates are forecast to stabilize and even lower slightly through the end of 1990, according to Newton, MA-based Cahners Economics.

Strong domestic economic growth and investment in the first quarter of 1990, rising foreign interest rates, and expectations of higher inflation rates contributed to the early-1990 rise in interest rates. However, lower inflation rates will steady interest rates through the last half of 1990, says Kermit Baker, director of economics for Cahners Economics.

Traditionally stable Japanese interest rates have risen 1.5 percentage

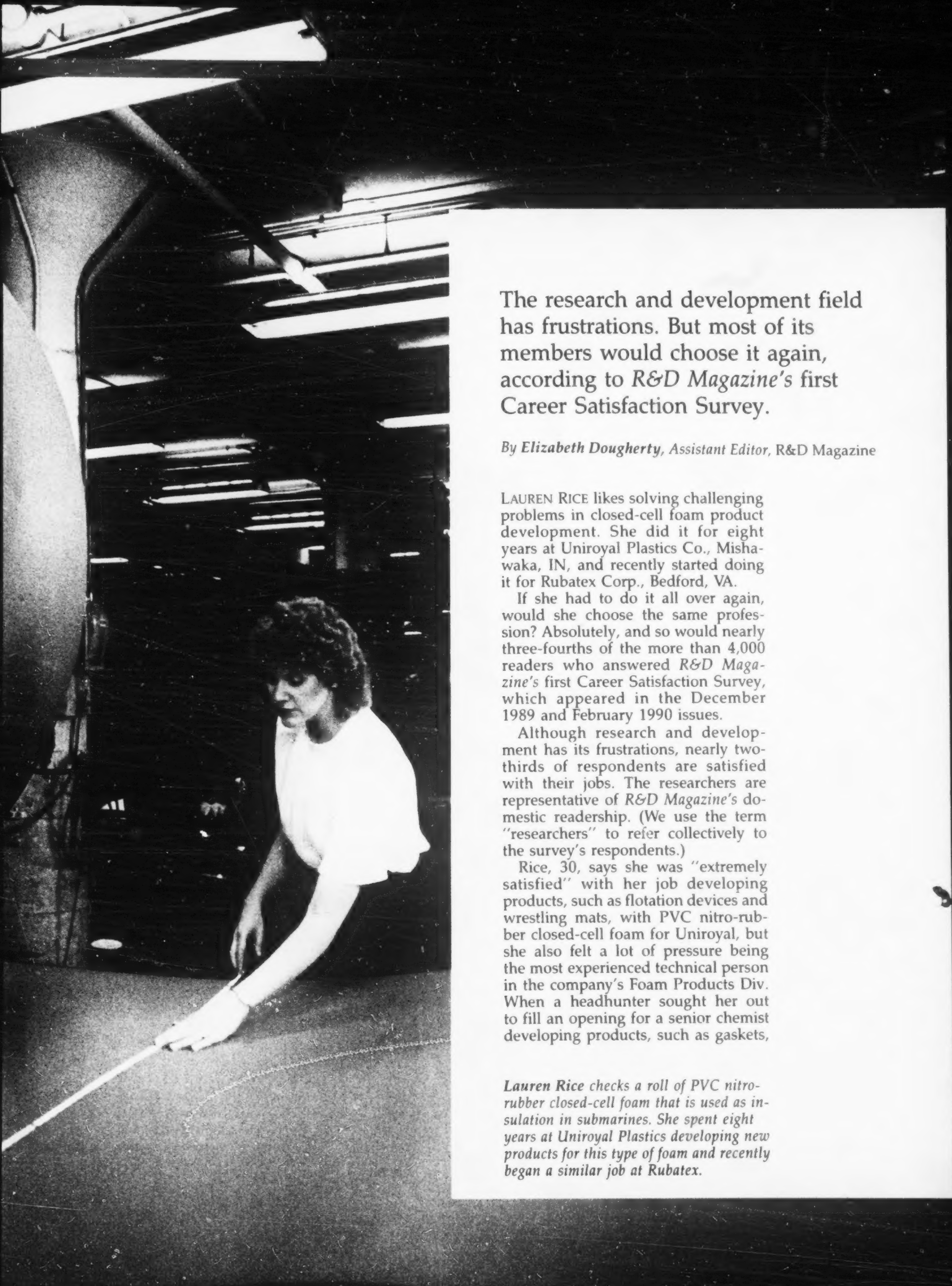
CAREER SATISFACTION

Would You Do It Again?

R D

Here's what you tell us about R&D

- ✓ Three out of four researchers would choose R&D again.
- ✓ Two out of three researchers are satisfied with their jobs.
- ✓ Best part of the job: solving challenging problems.
- ✓ Biggest beef: too much bureaucracy.
- ✓ Most employers do not reward researchers and managers equally.
- ✓ Nearly half of R&D employers are not open to new ideas.



The research and development field has frustrations. But most of its members would choose it again, according to *R&D Magazine's* first Career Satisfaction Survey.

By ***Elizabeth Dougherty****, Assistant Editor,* R&D Magazine

LAUREN RICE likes solving challenging problems in closed-cell foam product development. She did it for eight years at Uniroyal Plastics Co., Mishawaka, IN, and recently started doing it for Rubatex Corp., Bedford, VA.

If she had to do it all over again, would she choose the same profession? Absolutely, and so would nearly three-fourths of the more than 4,000 readers who answered *R&D Magazine's* first Career Satisfaction Survey, which appeared in the December 1989 and February 1990 issues.

Although research and development has its frustrations, nearly two-thirds of respondents are satisfied with their jobs. The researchers are representative of *R&D Magazine's* domestic readership. (We use the term "researchers" to refer collectively to the survey's respondents.)

Rice, 30, says she was "extremely satisfied" with her job developing products, such as flotation devices and wrestling mats, with PVC nitro-rubber closed-cell foam for Uniroyal, but she also felt a lot of pressure being the most experienced technical person in the company's Foam Products Div. When a headhunter sought her out to fill an opening for a senior chemist developing products, such as gaskets,

Lauren Rice *checks a roll of PVC nitro-rubber closed-cell foam that is used as insulation in submarines. She spent eight years at Uniroyal Plastics developing new products for this type of foam and recently began a similar job at Rubatex.*

The majority of researchers like what they do, especially solving challenging problems.

with closed-cell foam at Rubatex, she decided to go where she could work with more experienced researchers.

"A lot of people would dream about being in that position [being the most experienced researcher], but with two small children, I don't need any more pressure," Rice says. Her daughter is 2½ years old; her son is 5½ years old. Her husband, a purchasing agent, planned to look for a job after the family moved to Virginia at the beginning of June.

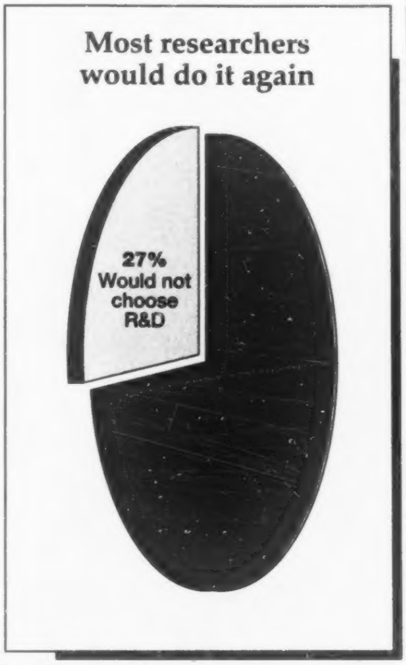
"I liked my job. That's why I chose a similar position," she says. "I don't want to get out of the business."

After earning a bachelor's degree in chemistry from Olivet Nazarene Univ., Kankakee, IL, Rice worked as a PVC compounding technician for five months and considered teaching or working on her doctorate. She "fell into" her job at Uniroyal when her father-in-law referred her to the firm.

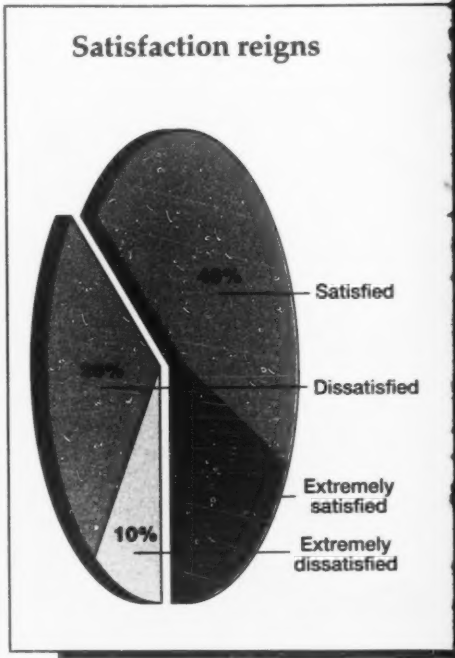
At Uniroyal, she went through five titles. "My responsibilities were the same all along. It was just a matter of money," says Rice, who fell into the same salary range—between $40,000 and $49,999—as about a fourth of the survey's respondents.

Rice likes the challenge of developing new products. "You have a different type of pressure. You're not fighting fires," she says. "You can be a lot more creative. This gives you more freedom."

Solving challenging problems is cited most frequently as one of the three most satisfying job aspects (see accompanying figures). This is ~~true in~~ all age groups and for researchers in industry, government, and consulting. University researchers, however, list the ability to work independently above solving challenging problems.



Nearly three-fourths *of researchers say if they had to do it all over again, they would still choose R&D.*



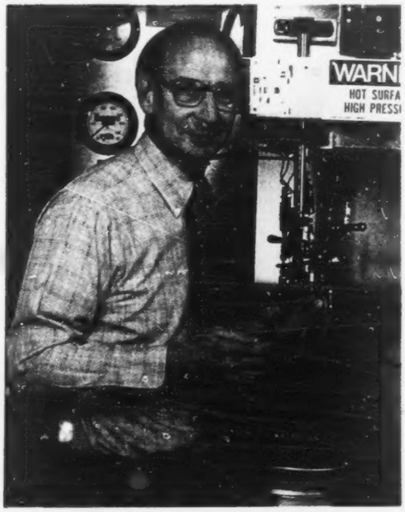
Nearly two-thirds *of researchers are satisfied with their current jobs. Fully 18% are extremely satisfied.*

The ability to work independently, along with "doing what I'm good at" and "the people I work with," are the next most often cited satisfying job aspects. As researchers get older, they are more likely to include "doing what I'm good at" and "being recognized in my field." The ability to work independently and a flexible schedule, two of Rice's choices for most satisfying job aspects, are cited more often by women than men.

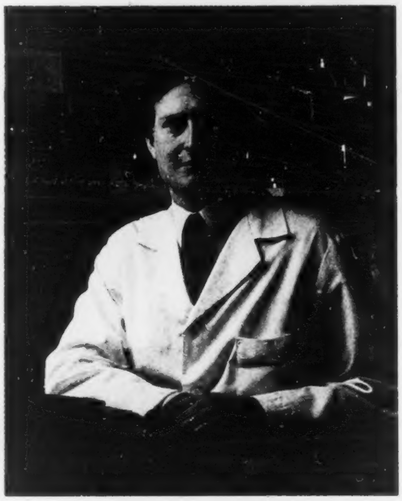
"I love doing chemistry—using my creativity and innovativeness to produce something new or modify something that could have a global impact is exciting!" says C.J. Opalka, a senior research chemist at Sterling Research Group, Rensselaer, NY.

Gary Douglas, a mechanical design engineer at Rockwell Power Systems, who is contracted to Sandia National Laboratories, Albuquerque, NM, says of his job—"Independence, appreciation, good pay. All this and fun, too!" Douglas has cradle-to-grave machine design and project management responsibilities. "I encourage all young people I know to choose the engineering profession."

Resa Brna, a chemist at Air Quality



"I feel very fortunate to have the opportunity to work on problems of global importance in an organization that has both the resources to attack these problems and a firm commitment to R&D," says Carl Scouten, 40, a senior scientist at Amoco Oil Co., Naperville, IL.



"Americans need to work harder if we want to compete with the Asians," says Steven Schill, 31, a product manager for Leybold Inficon Inc., East Syracuse, NY.

Services, Pittsburgh, says—"I have always wanted to be a chemist, even when I was told by my high school guidance counselor that I couldn't."

"I like to apply what I learned in school and actually see it work," says Sarah Ann Gallagher, a scientist at Sherwin-Williams, Cleveland.

Jay Cheek, a research physicist at the U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, says—"Because of some of the things I've done, the country is in some small way a better place to live. What more can one ask from his chosen profession?"

Frustration

Nearly 60% of the respondents work for organizations with 500 or more employees, and 15% work for the government.

It's not that surprising then that "too much bureaucracy" is a runaway favorite choice for one of the three least satisfying job aspects. About half the respondents in industry and at universities and about four out of five government employees cite this frustration (see accompanying figures).

"Senior 'researchers' don't do much research these days," says David Schryer, a research chemist for NASA Langley, Hampton, VA. "Instead, we hustle for funding, go to meetings, and write reports. This is not unique to NASA, but is fairly common throughout science."

"When you work for a big company (they're all the same), the paperwork cycle is long, and there are a lot of processes that you have to go through to get things implemented," says Gail Brinkman, an engineering chief at General Dynamics, San Diego.

Vic Gill, a manager at Westinghouse, Cincinnati, says—"The demands on a chemist are more legalistic and bureaucratic than technical, which is the primary reason one enters the field."

Not enough appreciation, no advancement opportunities, and inadequate staff are the next most frequently cited least satisfying job aspects after too much bureaucracy.

"The profession is satisfying," says Janice Chambers, an associate professor of biology at Mississippi State Univ., Mississippi State. "The red tape and lack of recognition for hard work sometimes becomes demoralizing."

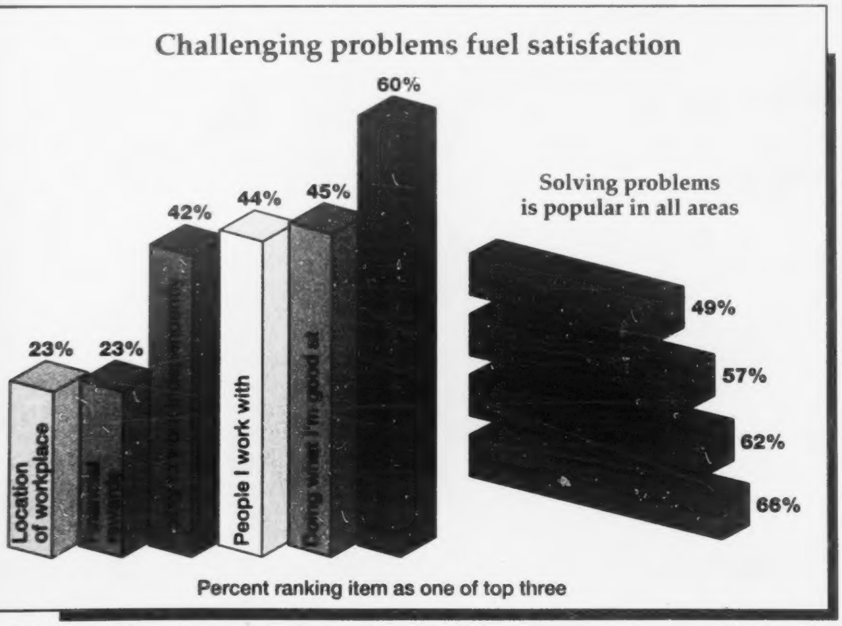
"Promotion to upper level management is very difficult for R&D people," says Bob Crooks, a chemist at Plasti-Kote Co. Inc., Medina, OH. "It's almost always sales, marketing, and finance people who are promoted."

Many researchers don't enjoy living with a negative image. "Our society denigrates scientists," says one chemist. "You're either a 'mad scientist' or a weirdo nerd." A technical director adds—"Chemists have become the bad guys in industry and are burdened with too many regulations."

Lack of funding and low salaries are pressing problems.

"It bothers me that an *average* lawyer or MBA makes more money for a field that is much less demanding and far less useful to society in the long run," says Barry Neyer, a senior diagnostic specialist at EG&G Mound, Miamisburg, OH.

John Hunt, a professor of genetics at Univ. of Hawaii, Honolulu, says—



Challenging problems fuel satisfaction

***Solving challenging problems** was the top choice when researchers were asked to list the three most satisfying aspects of their jobs (left). This is true in industry, government, and consulting settings (right). It was second only for university researchers, who ranked working independently as their top choice.*

'Too much bureaucracy' tops researchers' list of least satisfying job aspects.

"We must focus our efforts on the education system," says John MacPhee, 48, director of R&D sensor technology at Ciba Corning Diagnostics Corp., Medfield, MA. "More and more students know less about the great opportunities in the 'real' industrial work. Industry can help by working with the educators."

"The dependence on extramural funding to do research makes university research unattractive. The Federal funding (NIH, NSF) peer review system only worked where there was lots of money. Now innovation and true research are being stifled."

Competitive edge

Although the survey did not ask specifically about issues like competitiveness, industry took a beating for poor, short-sighted management. Researchers often expressed concern over the effects of management's approach to research on product quality and the nation's competitiveness.

"America is losing its technological edge to a glut of MBA graduates whose idea of long-range planning is to keep stockholders happy for another month," says one chemist.

"I wish business management in the U.S. had a better understanding of the engineering/product development process. America would be more competitive if the MBAs were MEs also," says Jim Dockendorff, a transducer design engineer at Stavely Sensors, East Hartford, CT.

Sterling Beck, a physicist and development engineer at Boeing Aerospace & Electronics, Seattle, says—"It is getting more difficult to do a job right! With the strong emphasis on profit, quality is increasingly stifled."

The effects of leveraged buyouts, mergers, reorganizations, and corporate growing pains also are being felt in the R&D ranks.

"The joy of the work outweighs the pain of the merger. The post-merger years have been painful for all at Unisys," says one manager at the company's Roseville, MN, location.

Michael Fath, who works in market development for Nova, Stow, OH, lists continuous reorganizations as the least satisfying aspect of his job, but he would pick R&D again. "I still enjoy 'selling science,' even in today's atmosphere of MBAs, bean counters, and corporate buyouts," he says.

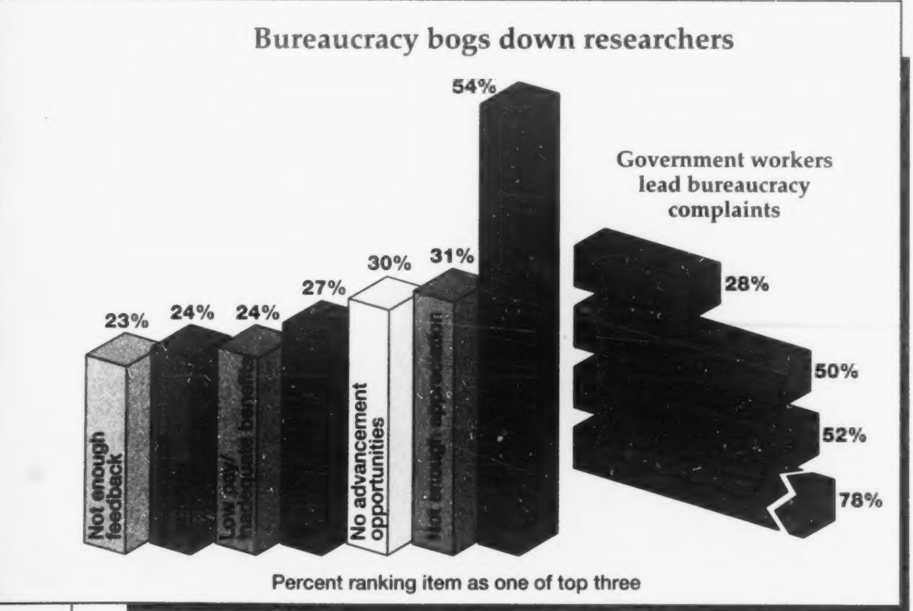
One industrial researcher says—"Our division has had three 'reorganizations' (layoffs) over the past five years that did not touch the hierarchy. The 'working stiffs' are fewer, the work load is heavier, and the urgency greater. Most of our problems are the result of accounting-oriented management, which views engineering, R&D, etc. as an expense to be minimized instead of an investment to be optimized (and exploited)."

Rewarding research

Employers' favoring managers over technical personnel is a bone of contention for many researchers.

Less than a third of respondents agreed that their employers "offer researchers the same rewards and opportunities to advance that it offers managers" (see accompanying figure). Respondents in consulting and at universities are the most likely to agree, while those in industry and government are least likely to agree.

"Promotion opportunities at the top of large corporations clearly go to peo-



Too much bureaucracy tops the list of researchers' three least satisfying job aspects (left). About half of industry and university researchers and nearly four out of five government workers rank this frustration in the top three (right).

Short-sighted management is hurting product quality and overall competitiveness, researchers say.

ple from financial or legal backgrounds, who are certainly no brighter nor do they work harder or better than good scientists and engineers," says M.C. Hamlyn, a technical manager at Allied Fibers, Moncure, NC.

Douglas Chapman, a quality assurance manager at Corn Products, Winston-Salem, NC, says—"The hardest bridge to cross seems to be from 'technical person' to 'management person,' especially in others' minds."

One researcher says: "A scientist becomes a kind of idiot-savant, isolated in the laboratory, where he is sidetracked from any possibility of ever taking on true managerial responsibilities. Meanwhile, people who have no concept of technology, or science, and are often afraid of it assume leadership roles."

Only a fourth of the researchers at the midpoint of their careers (15 to 19 years) agree that their employers offer researchers the same rewards and opportunities to advance that they offer managers. In contrast, two-thirds of those who have been in the profession fewer than five years or in it 35 or more years agree.

Researchers who make less than $20,000 (39%) or more than $70,000 (45%) and those who work at an organization with fewer than 50 employees (45%) also tend to agree that their employers offer researchers the same rewards and opportunities to advance that they offer managers.

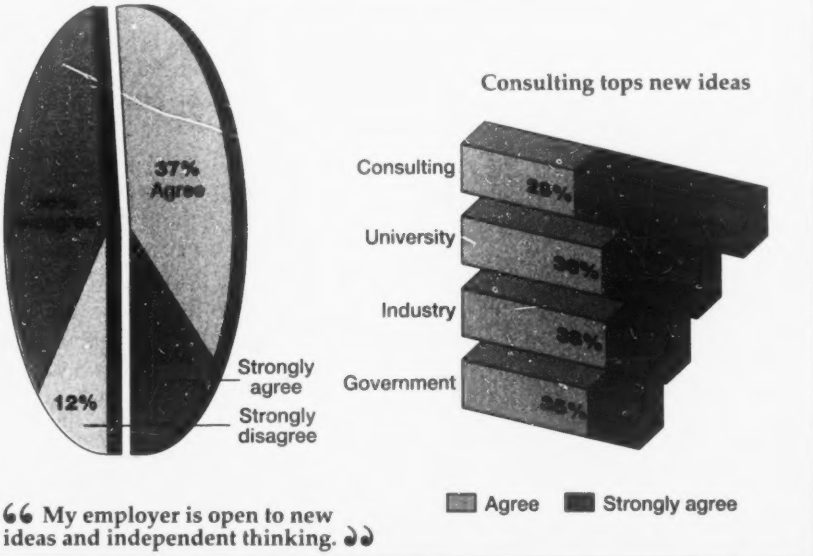
About 62% of respondents say their employers offer management training. Fully 85% pay for continuing education. "My company paid for [me to earn] an MBA in operations management," says Richard Kaner, 41. "Six months later, a position opened up, which I tried for and got, that lets me utilize my new degree." Kaner is a statistical quality control coordinator for Stepan Co., Chicago.

With regard to new ideas, the cup is slightly more full than empty, but not much.

Only 52% of researchers agree that their employers are open to new ideas and independent thinking (see accom-

"Chemistry is certainly not financially rewarding, and chemists are regarded as oddballs," says Stan Hunter, 65, director of chemistry and materials at Sierracin/Trans-Tech Div., Sylmar, CA. "I actively discourage anyone from considering a career in the sciences. I say, 'Make money, not progress.' "

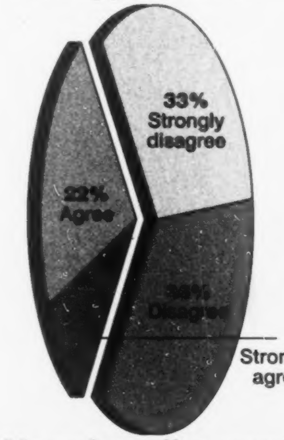
New ideas and independence



"My employer is open to new ideas and independent thinking."

Slightly more than half (52%) *of researchers agree that their employers are open to new ideas and independent thinking (left). Consultants, who often are self-employed, and university researchers agree most often (right).*

Rewards and opportunities



"My employer offers researchers the same rewards and opportunities to advance that it offers managers."

Less than a third *of researchers say their employers offer researchers and managers the same rewards and opportunities.*

Employers' favoring managers over technical personnel is a bone of contention for many researchers.

panying figures). In agreement are 72% of consultants, 60% of university researchers, 52% of industrial researchers, and 45% of government employees.

"New ideas are encouraged by giving awards in quarterly company meetings," says Hal Merritt, a technical associate at Planar Systems, Beaverton, OR.

Those who have worked for their employers between five and 19 years (47%) least frequently agree that their employers are open to new ideas, while those who had worked for their employers fewer than five years (59%) or 35 or more years (62%) most frequently agree. Researchers who earn less than $20,000 (58%) or more than $70,000 (63%) also tend to agree.

Researchers in organizations with fewer than 50 employees (64%) most frequently agree that their employers are open to new ideas and independent thinking. Fewer than half (46%) of the respondents in departments with more than 500 scientists, engineers, or professors agree.

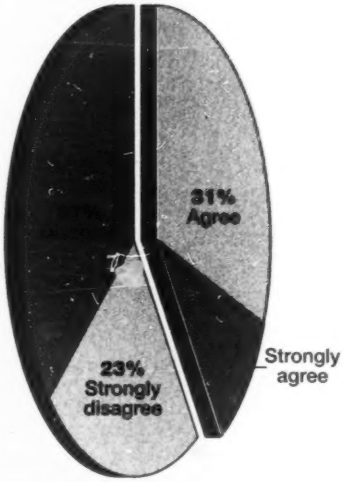
Almost 60% of respondents say their employers have a formal mechanism for channeling new ideas. These channels include proposals, memos, departmental meetings, patent applications, and presentations.

"Scientists fill out research proposals or 'idea note' forms," says J.K. Borchardt, a senior research chemist at Shell Development, Houston. "Periodically, the stack of these is evaluated. About 25% are initiated."

Companies without formal channels often have informal channels.

"Things 'filter up' through informal conversations," says Phil Hamilton, a staff scientist at CNS Research, Cambridge, MA, a company with approximately 45 employees.

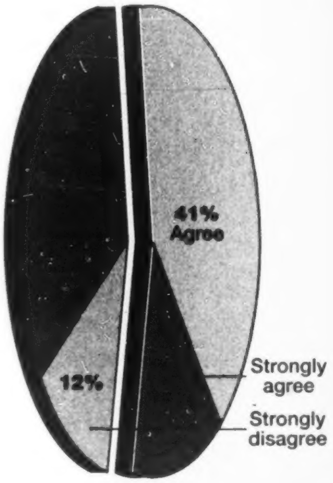
Organizational goals



"My employer effectively communicates its organizational goals to me."

Overall, fewer than half of researchers (41%) say their employers effectively communicate their organizational goals.

Job feedback



"My employer provides feedback regarding my job performance."

A majority of researchers (55%) agree that their employers provide feedback regarding job performance.

Eveready Battery Co. Inc., Westlake, OH, does not have a formal mechanism for channeling new ideas, says Andy Pattantyus, a senior engineer. "New ideas have to be sold hard, like swimming upstream," he says. "It's not a job for the meek."

James Hazen, a research supervisor in BASF Corp.'s Chemicals Div., Research Triangle Park, NC, says he can try new ideas "as time allows."

Some formal channels work; others don't, say researchers. One industrial chemist says his company has a formal mechanism "on paper. But in practice, this mechanism is ignored. Ideas come from the top down."

Knowing the game plan

Overall, 41% of researchers agree that their employers effectively communicate their organizational goals (see accompanying figure). Researchers who have been in the profession 35 or more years (47%) or who have worked for their employers 35 or more years (56%) agree more frequently than those who have been in the profession between five and 19 years (38%) or with their employers between five and 19 years (38%).

More than half of the respondents

"My career has been challenging and satisfying," says Marvin Wishman, 65, chemical and analytical research director at Phillips Fibers Corp., Greenville, SC. "Thirty-five years ago, synthetic fiber was in its infancy. A career in one field is hardly possible any longer."

Nearly half the respondents say their employers are not open to new ideas and independent thinking.

"I have had a very gratifying career as a metallurgical engineer. My son is now a materials/metallurgical engineer," says Jim Staley, 55, a senior technical consultant for Aluminum Company of America, Alcoa Center, PA. "My internal recognition came only after many years of 'paying my dues.' I was recently recognized by receiving Alcoa's top technical award."

making $70,000 or more (54%) as well as nearly half of those making less than $20,000 (49%) say they know their organizations' goals. Only 31% of those making between $20,000 and $29,999 say their organization effectively communicates its game plan.

More than half the researchers in organizations with fewer than 50 employees (52%) say organizational goals are effectively communicated to them.

Knowing how you do

A majority of researchers (55%) agree that their employers provide feedback regarding job performance (see accompanying figure).

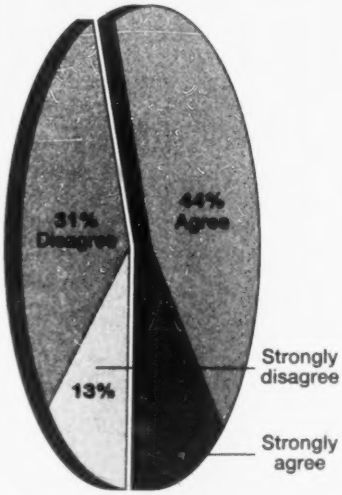
Researchers making less than $20,000 (62%) or making $70,000 or more (63%) agree most frequently that they receive feedback about job performance. Fewer than half (44%) of those making between $20,000 and $29,999 say they receive feedback.

A majority (56%) also agree that their employers are objective in evaluating job performance (see accompanying figure).

Researchers under age 30 (66%) and researchers between the ages of 30 and 39 (61%) agree more frequently than other age groups that they are evaluated objectively.

Researchers who have been in the field fewer than five years (63%), those who have worked for their employers for fewer than five years (63%) or for 35 or more years (64%), and those earning $70,000 or more (67%) also frequently say their employers evaluate them objectively.

Objective evaluation



“ My employer is objective in evaluating my performance. ”

A majority of researchers (56%) agree that their employers are objective in evaluating job performance.

Some researchers are fed up and would choose an entirely different field, such as law or business. Others, who say they would not choose the same profession, frequently indicated that they would choose a different *scientific* area, often medicine or biomedical research. Often researchers felt that they could have had a greater impact helping people instead of improving things.

Physicist A.J. Benjamin, a senior technical specialist at Northrop Corp., Brea, CA, says if he had to do it over he would go into medical research.

P. Lagus, president of Lagus Applied Technology Inc., San Diego, also would go into medicine. "You can be of more use to society and have no shortage of clients," he says. Diane Phelan, a senior scientist working in electrochemistry at Leeds & Northrup, North Wales, PA, says she would have obtained a PhD in biology and conducted cancer research.

B.L. Windsor, a scientist at Parke-Davis, Ann Arbor, MI, says she would go into veterinary medicine instead of chemistry. "My major was in chemistry, but after working, I found that I also have a definite talent in handling animals and developing surgical techniques," she says.

Mark McKinley, a team coordinator at Micro Encoder Inc., Kirkland, WA, says his second-chance career choices include geology, archaeology, and medicine. "I would rather develop science to help people than develop military weapons to kill them," he says.

Dave Pettigrew, a senior chemical engineer at Magnavox, Fort Wayne, IN, says he "probably would have gone into engineering disciplines instead, since most ideas and concepts need a firm engineering basis, as well as a scientific basis."

Some researchers just can't get enough of what they do. R.P. Nordgren at Shell Development Co., Houston, says—"Industrial R&D has been a great career for me. I am retiring after 27 years and will teach at Rice Univ."

"I have been with my present employer 23 years," says A.J. Roccati, a staff scientist at EG&G Inc.'s Washington Analytical Services Center, Rockville, MD. "I am 70 years old and haven't retired because I enjoy my work." **R&D**

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NASA's Byron Lichtenberg loads a crystal-growth experiment aboard a mock-up of Spacelab

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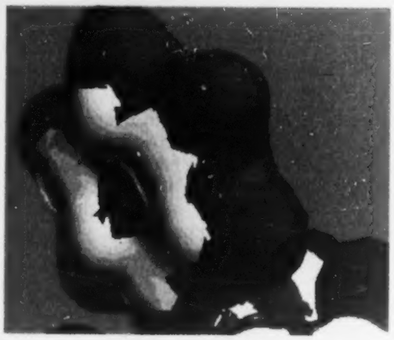

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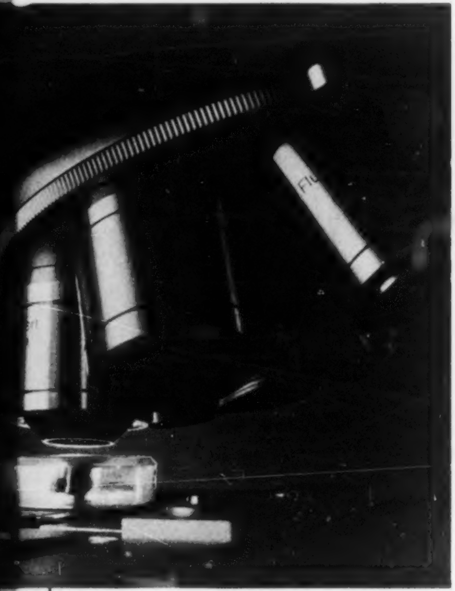
*NASA's **Byron Lichtenberg** loads an experiment aboard a Spacelab mock-up. NASA plans to launch Spacelab aboard* Columbia *in December. Critics, however, fear that NASA's mission for the 1990s already is off course. See story on page 42. Photograph by Neil MacDonald.*



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R&D BUSINESS

Defense R&D spending shoots up in 1st quarter

AFTER RISING a meager 0.4% in the last quarter of 1989, defense expenditures for contractual research and development rose 8.7% in the first quarter of 1990 above what was spent in first-quarter 1989.

This amounts to a seasonally adjusted annual figure of $32.4 billion, or 5.2% above 1989's total spending of $30.8 billion.

National defense purchases amounted to an annualized $309 billion in the first quarter of 1990—up 3.5% over a year ago. When adjusted for inflation, purchases actually rose only 0.6%. This rate accounted for fewer government purchases of some types of military equipment.

According to the Electronic Industries Assn., the budget for research, development, test, and evaluation (estimated at about 90% of the total defense R&D budget) will decline from $39.3 billion in 1988 to $28.8 billion in 1999 (measured in FY90 dollars).

—Julie Handelman

Japan wins larger piece of U.S. aerospace pie

THE JAPANESE aerospace industry's 10% share of Seattle-based Boeing's 777 program is the largest share of any U.S. aircraft development ever captured by an "outside" company.

The 777 program is a twin-engined, long-range aircraft capable of carrying 350 passengers. The advanced design is expected to incorporate composite structural components, fiber-optic cables, and integrated avionics.

However, the Japanese firms, Mitsubishi, Kawasaki, and Fuji Heavy Industries, felt the pinch of development costs when they were unable to meet the 25% equity partnership requirements that they initially wanted.

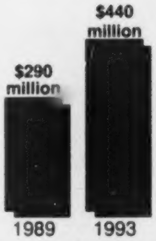
For a 25% equity share, Boeing required at least $1 billion of the $4 billion estimated development cost. The Japanese firms, already heavily committed in money and staffing to developing the FS-X fighter, didn't have the $1 billion or the additional engineers to support a 25% equity share.

Mitsubishi also recently announced a joint materials, aircraft engine, and aerodynamics research program with Germany's Daimler-Benz AG.

Total Japanese involvement in the 777 is expected to go beyond the Boeing-Mitsubishi-Kawasaki-Fuji arrangement. Three Japanese aircraft engine companies are bidding on engines for the 777. Toray Industries, a supplier of carbon composites, and the joint venture of Dublin, CA-based Hexcel and Dainippon Ink & Chemicals, a supplier of honeycomb and advanced composite panels, are potential suppliers of composite structures.

Other Japanese companies that already supply parts for Boeing's existing 767 program would be expected to get follow-on contracts. *—Tim Studt*

Moderate growth seen for x-ray fluorescence



CONTINUING technical innovations in x-ray fluorescence instruments will increase this market at an annual rate of more than 11% to $440 million worldwide in 1993, according to Strategic Directions Intl., a Los Angeles-based analytical-instrument consulting firm.

This total includes wavelength- and energy-dispersive x-ray fluorescence and x-ray microanalysis accessories used on electron microscopes and microprobes.

Top 1991 R&D spenders are a rerun of 1990

THE TOP 10 corporate R&D spenders next year will be the same companies who were the top 10 spenders in the world in 1990, according to a study by Schonfeld & Associates, an Evanston, IL-based management consulting firm.

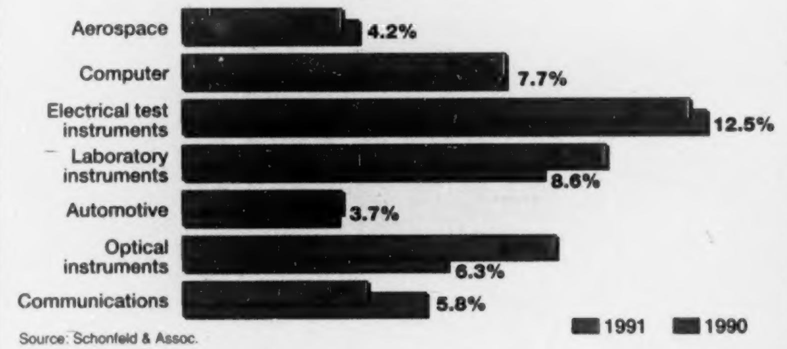
The ranking of the top five spenders won't change at all, with General Motors ($5.975 billion) barely edging out IBM ($5.969 billion). Hitachi, Matsushita, and Ford Motor round out the top five, followed by AT&T, NT&T, NEC, Toshiba, and Philips NV.

The computer industry is forecast to be the biggest R&D spender in 1991 at $21.7 billion, up 9.7% over R&D spending in 1990.

Aerospace R&D is starting to show some effects of the defense slowdown, with the biggest spender, United Technologies, forecast to increase its R&D spending by only 4% to $1 billion.

For a copy of *R&D Ratios & Budgets*, ($295): 708/869-5556. ☐

No big changes forecast for 1991 R&D spending
(R&D as percent of sales)

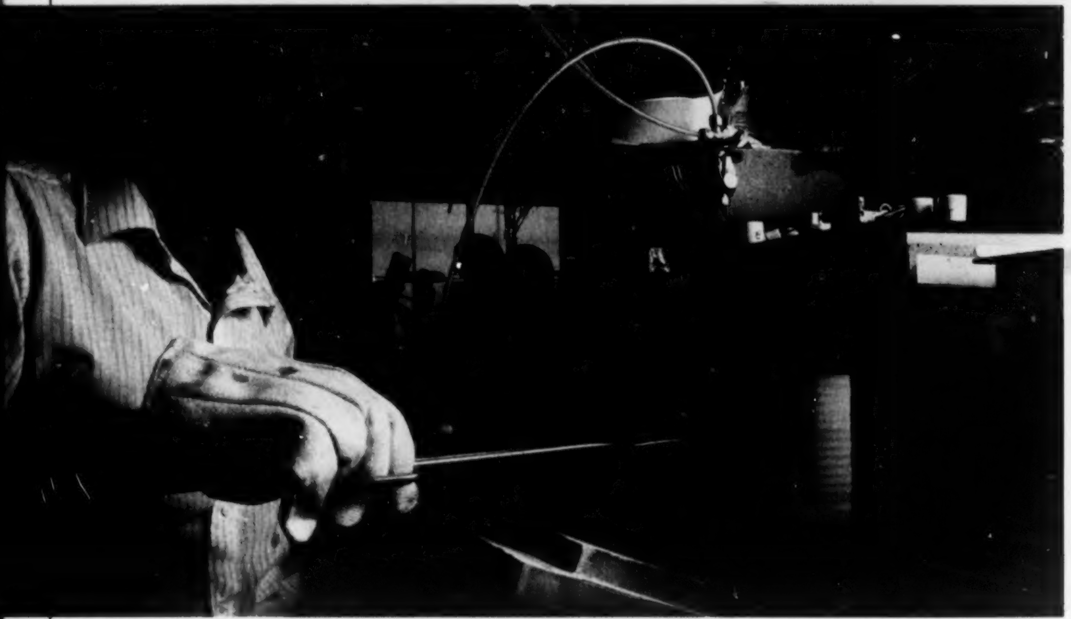


Source: Schonfeld & Assoc.

***Changes in R&D spending** forecast for 1991 reflect lower defense spending, a maturing of the computer industry, and increased use of optical instruments in quality control.*

R&D

NEWS OF SCIENCE AND TECHNOLOGY



***Chemist** Ed Nazzal of IBM's Almaden Research Center, San Jose, CA, heats a sample of oxides to turn it into a ceramic superconductor. The U.S. has a formidable HTS research program in place, but a report by the U.S. Office of Technology Assessment questions whether industry is in HTS for the long haul to commercialization.*

Photo: IBM/Don Kenney

SUPERCONDUCTIVITY

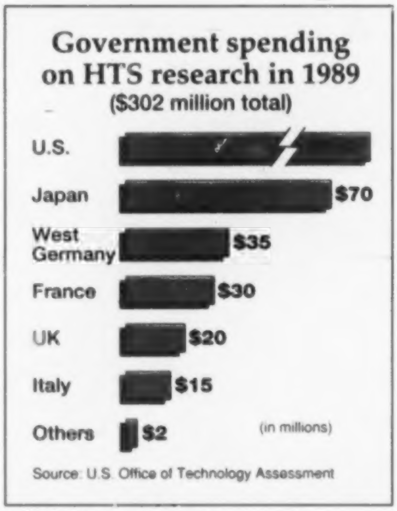
Is U.S. vulnerable in HTS race?

HIGH-TEMPERATURE superconductivity (HTS), one of the most exciting scientific developments in the 1980s, will be the most challenging test to U.S. competitiveness in the 1990s, according to a report by the U.S. Office of Technology Assessment (OTA).

While the government agency believes that the U.S. has responded well to the early challenge, it also questions whether U.S. companies are in a position to go toe-to-toe with the Europeans and the Japanese in HTS commercialization.

"There is a serious question whether U.S. industry, as it is currently financed and managed, can compete in markets for these technologies in the next century," the report states. "HTS is a test case . . . of [U.S.] ability to look beyond the immediate future and sustain a consistent R&D effort over the long term."

The U.S. and Japan each spend about $220 million a year on superconductivity research. But in Japan the funding comes more from large companies and less from the government. In the U.S., the opposite is true.



Source: U.S. Office of Technology Assessment

***The U.S. government** outspends Japan on HTS research by nearly 2-to-1, but Japanese companies are in a better position for HTS commercialization, states the U.S. Office of Technology Assessment.*

This makes the U.S. program susceptible to budget cutbacks and changing priorities.

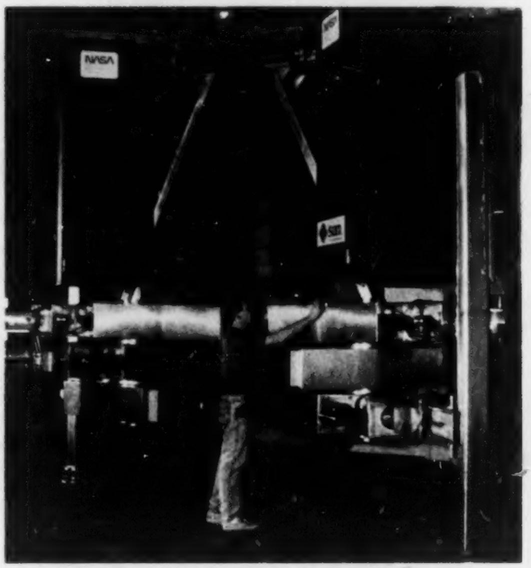
The Dept. of Defense is the largest supporter of HTS research, but the thaw in the Cold War could shrink this funding source.

"Government funding, especially through the Dept. of Defense, is not the most direct route to commercialization," says Bill Gallagher, manager of exploratory cryogenics at IBM Corp., Yorktown Heights, NY.

What is needed are more U.S. corporations to fund HTS research over the long term, a bolstering of university research, and coordination of the HTS effort at the national level, OTA states.

HTS products should begin coming to market in five years, but the significant products are 10 to 20 years away, says OTA. This is much longer than

Autonomous robot is ready to scale new heights



A researcher at Carnegie Mellon Univ., Pittsburgh, adjusts Ambler (autonomous mobile exploration robot), which is being developed for NASA for possible planetary and lunar exploration missions. A final version of Ambler will have a laser scanner for visual perception and an on-board computer for reasoning.

Ambler, with its 3-m-long (10-ft) legs, will be able to step over 1-m-dia obstacles on a 30-deg slope while keeping its body level. Although the robot is designed to traverse rough terrain, it will do so at a slow pace, covering about 1 km per day.

many large U.S. companies are willing to invest in a research program.

Small start-up firms need a large funding base to make it through the lean early years. There is concern in industry as to whether the small companies can survive living off their early products.

But for small companies the question is: What are the big U.S. corporations doing?

"The situation is competitive right now," says Gregory Yurek, president and CEO of American Superconductor Corp., Watertown, MA. "If we don't see the continued funding from the government and we don't see the large U.S. companies getting more involved, then we will start losing the competition."

Some say for the U.S. to succeed in HTS, the U.S. needs an industrial policy, an idea the Bush administration has opposed.

"I have some sympathy for those against an industrial policy," says John Hulm, chief scientist emeritus, Westinghouse Electric Corp., Pittsburgh. "But in the modern world, where other countries' governments are interfering, we probably need to do some interfering too."

"This really is a case of the U.S. vs. the U.S.," adds Ed Mead, manager of business development for superconductivity at DuPont Co., Wilmington, DE. "Are we going to be fat and sloppy and not move quickly or very well, or are we going to move assuredly?" *—Skip Derra*

OCEANOGRAPHY

Iron is seen as tonic for global warming

OCEANOGRAPHER John Martin says the simplest way to combat global warming is to pump some iron. Actually, to pump about 300,000 tons of iron into what amounts to 18% of the world's oceans.

The iron "fertilizer" would help phytoplankton in the ocean bloom, which in turn would absorb as much as 2 billion tons/yr of CO_2, according to Martin's estimates. This would put a big dent into the 3 billion tons/yr of CO_2 buildup in the atmosphere.

"It could have a huge effect," says Martin, director of Moss Landing (CA) Marine Laboratories.

Giving iron-poor oceans "a shot of Geritol" has been a pet idea of Martin's for two years now. "All you have to do is add a pinch of iron here and there, and the plants will bloom," he says.

But Martin is quick to add that iron fertilizing is only an idea. A lot of work still has to be done to explore fertilization sites and assess environmental effects.

"Iron fertilizing certainly is one way to increase the fixation of carbon in the oceans," says Roger Revelle, former director of the Scripps Institution of Oceanography, La Jolla, CA. "But the iron would have to be spread over an enormous area. Nobody knows how to do that." ☐

SPECTROSCOPY

Researchers aim new detector at the heart of nuclear matter

BRITISH AND FRENCH scientists are building the world's most sensitive gamma-ray detector.

An $8.5 million agreement between the UK Science & Engineering Research Council's Daresbury Laboratory, Warrington, and the French National Institute of Nuclear Physics and Particle Physics, Paris, calls for development, construction, and utilization of the Eurogam gamma-ray detector.

Eurogam is expected to be two orders of magnitude more sensitive than any other gamma-ray detector.

It will be used to study some of the most exotic forms of nuclear matter, including the super-deformed nuclear pulsars.

Eurogam, in addition to studying the limits of nuclei stability, will be novel in that it will be shipped between sites in England and France. Eurogam will be located at Daresbury for the first year after it is completed, and the 45-detector array will be connected to Daresbury accelerators and a recoil mass spectrometer for nuclear structure studies.

By its second year of operation, Eurogam will be built up to a 70-detector system. Then it will be moved to the French Vivitron accelerator, now under construction in Strasbourg. ☐

NONDESTRUCTIVE EVALUATION

Researchers adapt NDE systems for thick composites

AS INDUSTRY BEGINS to use composite parts in primary structural applications, there is a growing need to develop nondestructive evaluation (NDE) methods to inspect the parts.

Current NDE methods are useful in inspecting thin composites, but researchers are finding new challenges in developing systems for thick composites, says Glenn Light, manager of the NDE Assessment Section, Southwest Research Institute, San Antonio.

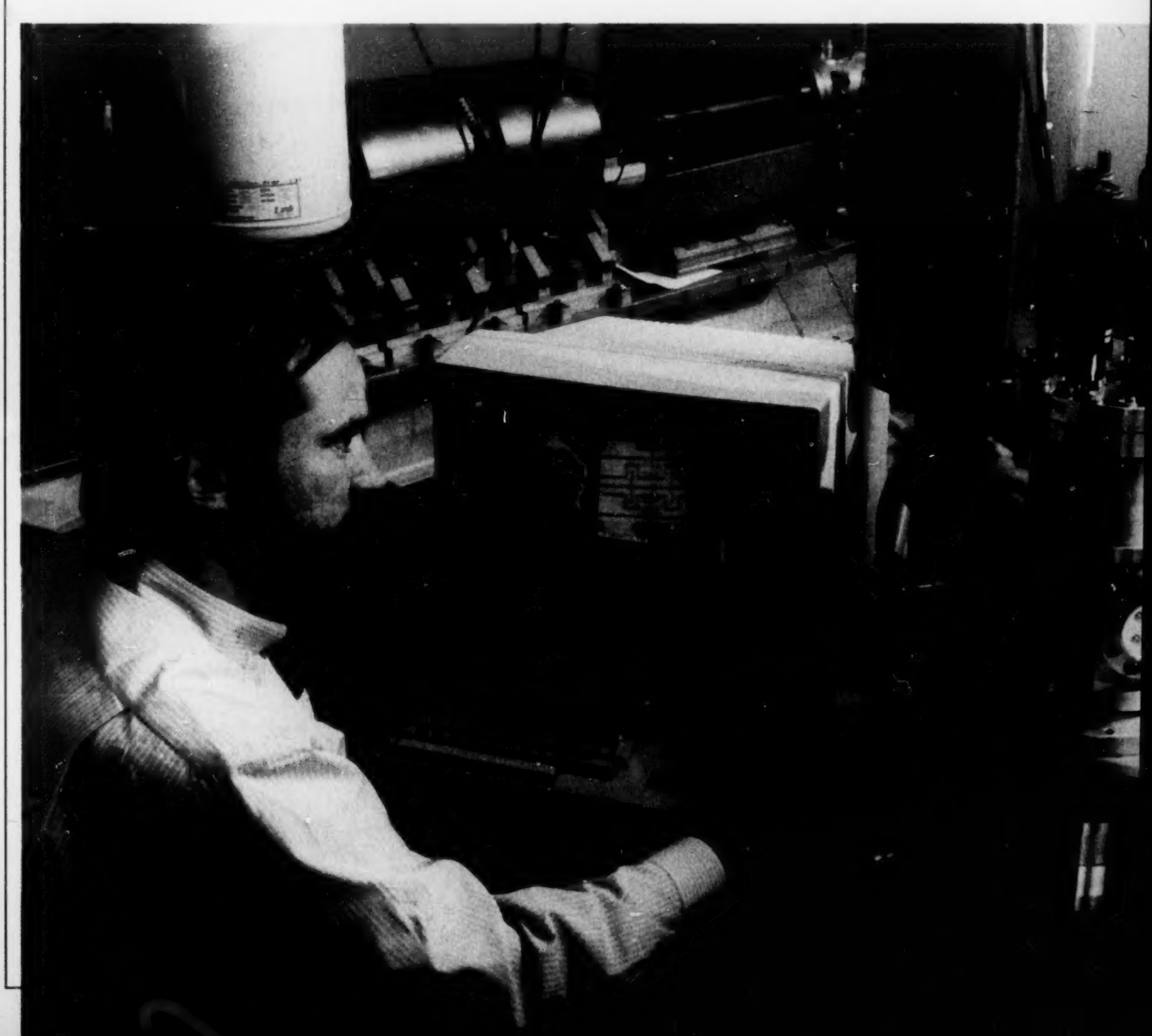
Primary structural applications of

Surface Science Pushes Theoretical Limits

R&D Perspectives

New microscopy and surface analysis instruments help you probe the composition and structure of materials.

*By **Tim Studt**, Associate Editor,* R&D Magazine



MICROSCOPY has advanced further in the past 10 years than it had in all the previous 300 years, since Antonie van Leeuwenhoek invented the compound optical microscope.

The past decade saw the development of microscopes that image individual atoms, microscopes that can peer inside a living cell without damaging the cell, and microscopes that let you watch crystals grow at 1,000 C.

Even Leeuwenhoek's basic light microscope (LM) has seen evolutionary breakthroughs with electronic imaging and video enhancements that improve its resolution and allow you to manipulate images.

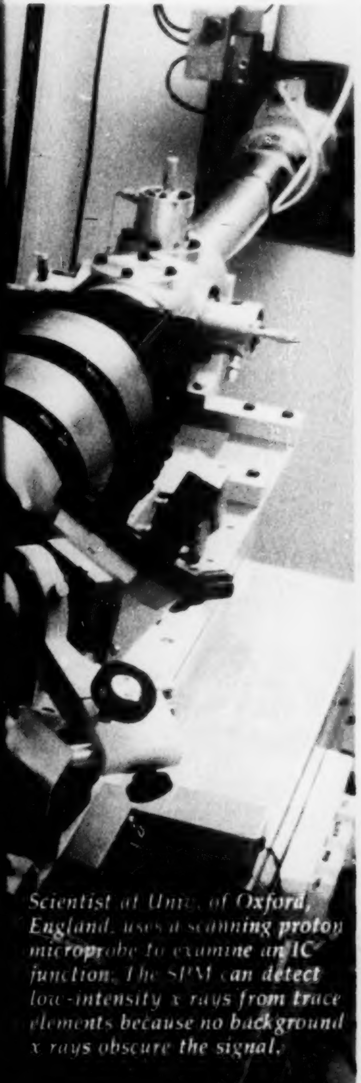
Research, such as that in near-field scanning techniques being performed at Cornell Univ., Ithaca, NY, also is bringing LMs into the performance realm of electron microscopes, says Ernst Keller, LM technical manager for Carl Zeiss Inc., Thornwood, NY.

The most significant event in microscopy is the availability of powerful and cost-effective electronic systems. By adding electronic imaging and analysis capabilities to a microscopy system, you can see and use more of the image information. None of the electron microscopes and scanning probe microscopes would have been possible without the development of electronic imaging systems.

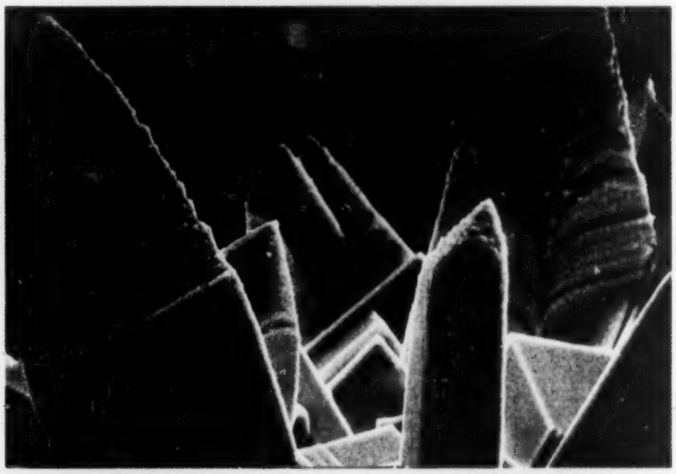
Four hot microscopes

Four microscopy systems giving you imaging capabilities that until now were not possible are confocal scanning microscopes, scanning tunneling microscopes, scanning force microscopes, and environmental scanning electron microscopes.

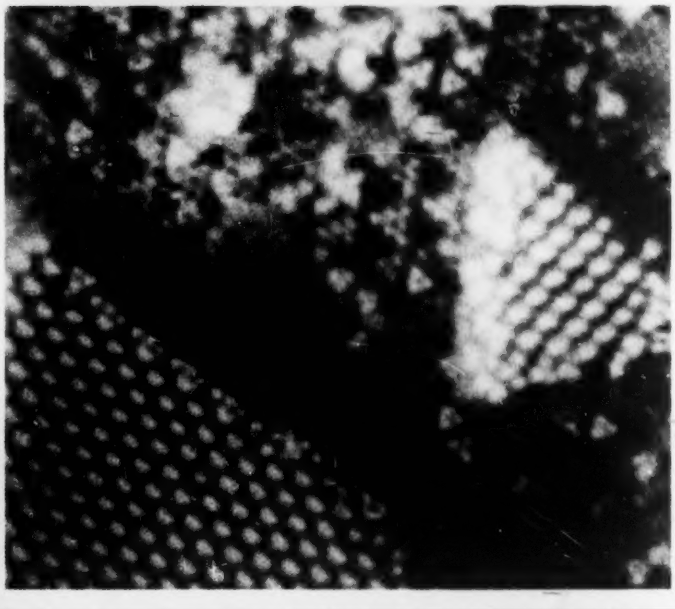
Confocal scanning microscopes: These microscopes let you generate 3-D images of a sample, both external and in-



Scientist at Univ. of Oxford, England, uses a scanning proton microprobe to examine an IC junction. The SPM can detect low-intensity x rays from trace elements because no background x rays obscure the signal.



These KCl crystals were condensed from gas at 600 C. An environmental scanning electron microscope allows you to observe their growth.



Three material phases (lower left, center, and upper right) of an Sn-induced reconstruction in a Si(111) surface are revealed in this UHV STM image. Image by Park Scientific Instruments.

You can literally 'walk' a confocal microscope through a sample as you image at different focal planes in it.

ternal features, without cutting or damaging the sample.

With a confocal microscope you focus your optics at one plane of a sample, electronically store the resultant image, move the focus down a few micrometers into the sample, and take another image. You can literally "walk" a confocal microscope through a sample as you image at different focal planes in it.

To construct a solid model, you then use a software package to recombine the images. Some models use up to 150 image slices.

The confocal concept relies on the focusing of a light source onto a sample through high numerical aperture lenses. This causes the light to approach the sample at angles that produce a thin plane of focus.

Light reflected from the sample passes back through the optic system, which focuses the beam through a pinhole aperture and onto a detector. Light reflected from above or below the plane of focus is blocked at the pinhole from reaching the detector, creating a high-resolution image with high contrast.

Confocal scanning microscopes are available with tungsten filaments or laser light sources. A tungsten source lets you image color samples, while the high intensity of a laser source provides images with high resolution and contrast.

Confocal laser scanning microscopes (CLSM) are especially useful in the imaging of delicate biological samples, such as those that can be stained with fluorescent dyes.

What's the difference?

SINCE MANY surface science techniques operate in microscope or microprobe (surface analysis) modes, when does a microscope stop being just a microscope and when does it become a microprobe?

"Microscopes only show you the morphology of a surface," says Charles Evans, president of Charles Evans & Associates. "By themselves they do not identify elements or molecules."

A microprobe provides information that's used to "tag" a constituent. In the process of obtaining this information, you also might be able to image the surface.

Microscopes: From macroviews to atomic views

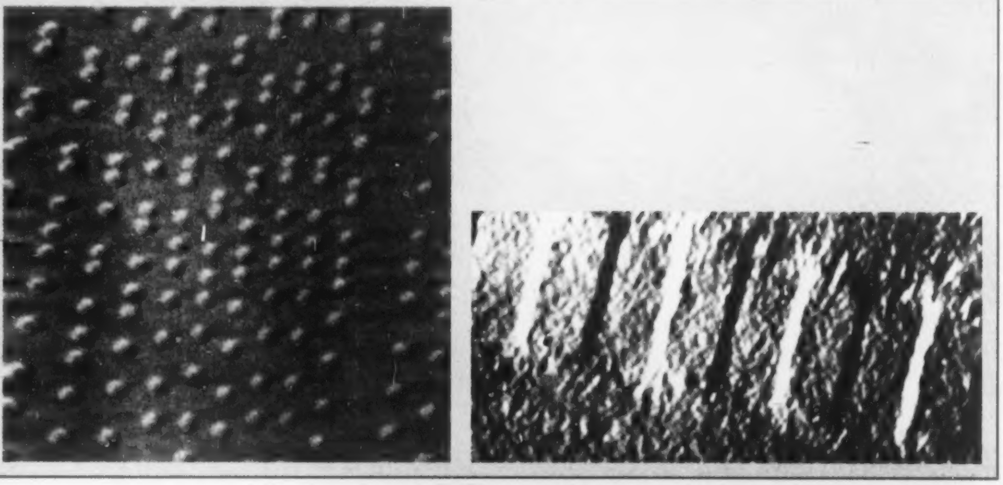
	Acronym	Magnification range, times	Resolution, nm	Analysis time[*], sec	NDT Yes/No	Operating voltage, eV	Environment, Vacuum/ Ambient	Approximate equipment cost (U.S. $)
Light microscope	LM	5 to 2,000	200	10	Yes	0	Ambient	$2,000 to $100,000
Scanning electron microscope	SEM	10,000 to 250,000	5	60	Yes[‡]	500 to 40,000	Vacuum/ Ambient[†]	$40,000 to $400,000
Scanning electron microscope/Field emitter	SEM/ FE	10,000 to 400,000	1.0	90	Yes[‡]	100 to 300,000	Vacuum	$200,000 to $600,000
Transmission electron microscope	TEM	1,000 to 1,000,000	0.15	300	No	30,000 to 1,000,000	Vacuum	$100,000 to $5,000,000
Scanning transmission electron microscope	STEM	100,000 to 1,000,000	0.5	300	No	1,000 to 50,000	Vacuum	$200,000 to $800,000
Scanning TEM with selective area diffraction	STEM/ SAD	1,000 to 1,000,000	0.15	30	No	30,000 to 1,000,000	Vacuum	$100,000 to $5,000,000
Scanning laser acoustic microscope	SLAM	10 to 500	1,000	60	Yes	0	Ambient	$600,000 to $800,000
Confocal scanning microscope	CSM	100 to 10,000	0.1	20	Yes	0	Ambient	$50,000 to $200,000
Scanning tunneling microscope	STM	5,000 to 10,000,000	0.0001	300	Yes[£]	0 to 1 V	Vacuum/ Ambient	$30,000 to $200,000
Atomic force microscope	AFM	5,000 to 2,000,000	0.0005	300	Yes	0	Ambient	$75,000 to $200,000

[*] Time listed is to acquire an image with no analysis required.

[†] Most SEMs are kept under vacuum, all measurements are made in vacuum.

[‡] Sample preparation may be destructive.

[£] STMs are generally nondestructive, but its probe beam may do damage.



Magnetization patterns of longitudinal (near left) and magneto-optic recording media (far left) are revealed with a magnetic force microscope by researchers at IBM. Both pictures have the same scales—each longitudinal bit is about 5-µm wide.

"CLSMs are just starting to be used in materials science analyses," says Barbara Foster, technical manager for Sarastro Inc., Philadelphia. "With the CLSM, we've imaged several millimeters in depth into styrofoam and have focused through thin films of copper."

Scanning tunneling microscopes: It has been eight years since IBM researchers in Zurich, Switzerland, built a scanning tunneling microscope and used it to reveal the first images of individual atoms. Today, commercial versions of STMs are available and, except for special analysis requirements, buying a commercial instrument is more practical and less expensive than building your own system.

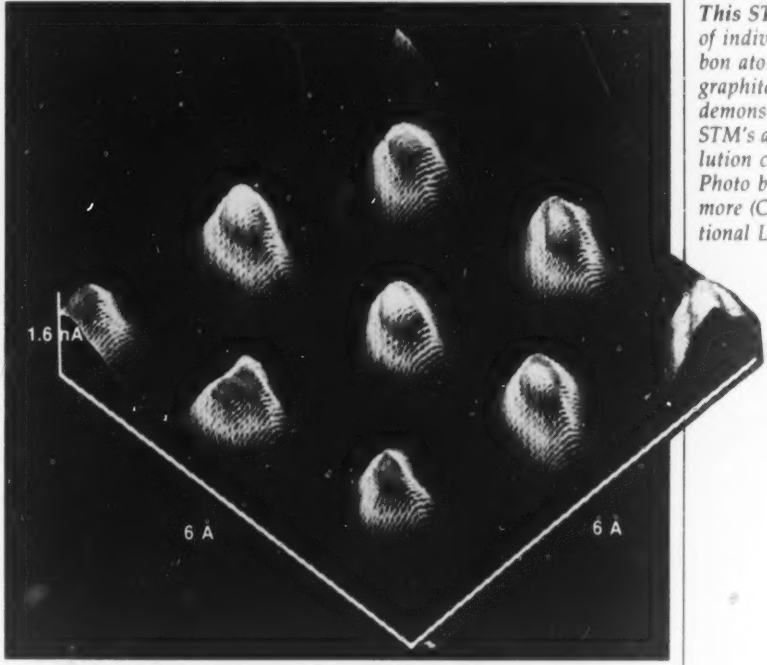
The commercial instruments include graphic workstations, software, and electron-tunneling spectroscopy tools.

Because STMs have become relatively inexpensive, they have become fairly common in labs. This has resulted in numerous journal papers that refer to STM analyses and further establish its credibility.

Still, the STM technique is not without its problems.

"STMs are a number of years away from being a tool that can be used off the shelf by anybody," says Rod Balhorn, a biochemist at Lawrence Livermore (CA) National Laboratory. Balhorn sees two basic problems:

1. Significant unresolved interactions still exist between the scanning tip of the microscope and the surface atoms or molecules being scanned. Com-



***This STM** image of individual carbon atoms on a graphite surface demonstrates STM's atomic resolution capabilities. Photo by Livermore (CA) National Laboratory.*

Watch your language

Auger effect: Transition of an electron in an atom from one discrete electronic level to an ionized continuous level of the same energy.

numerical aperture (NA): A measure of a lens's capability to gather light. NA = n × sinα, where n is the refractive index of the lens and α is the angle between the outer rays entering the lens and the axis.

resolution: The ability to detect two closely spaced objects as two distinct entities. For transmitted light R = λ/NA and for reflected light R = λ/2NA, where λ is the wavelength of light and NA is numerical aperture.

secondary ion: Particle (neutral atom or molecule, secondary electron, photon, and positive or negative ion) sputtered off a sample bombarded by a primary ion.

spectroscopy: Physics concerned with interpretation of electromagnetic spectra emitted or absorbed by a substance.

Using the scanning force microscopy technique, you get high-resolution images with little sample preparation.

plicated interactions occur in the surface structure when electrons are pumped into the orbitals of the atoms.

2. Researchers still are learning how to interpret the topographical images produced by STMs. Simple structures like carbon are readily imaged and explained. Complex fragile structures like DNA, however, are more difficult.

A principal application of the STM is the modeling of crystal surface structures. For example, Shirley Chiang at IBM's Almaden Research Center, San Jose, CA, uses an STM to determine atomic and molecular positions, which she compares to theoretical crystal structures.

Although STMs can operate in ambient environments, Chiang operates an STM in a UHV chamber so that samples can be transferred to a low-energy diffraction instrument for additional surface analyses. She also can transfer the samples to a deposition chamber and back again to observe the effects of various coating processes.

Scanning force microscopes: Scanning force microscopes, which include atomic force microscopes (AFM), scan a sharp cantilevered probe tip at atomic distances above a sample. The resultant tip force deflections from this close contact are used to describe the physical surface characteristics of the sample.

A family of scanning force microscopes has been developed that work on the principles of attractive forces, magnetic forces, electrostatic forces, thermal variations, conductive characteristics, friction forces, acoustic characteristics, and near-field optics.

For example, researchers can use a magnetic force microscope (MFM) equipped with a nickel wire cantilever tip to image the magnetization patterns of magnetic recording materials.

"The strength of the MFM technique is that you get high-resolution images with little or no sample preparation," says Dan Rugar, at IBM's Almaden Research Center.

Commercial AFMs already are available as options to the STM.

Environmental scanning electron microscopes: The ESEM eliminates two of the biggest limitations of electron microscopy: operating the sample at UHV and having to coat samples with conductive coatings. The ESEM uses a differential pumping scheme and a gaseous discharge detector to let you look at samples at up to 20 torr.

Recent upgrades on this system include addition of a sample heating stage that can heat samples to >1,000 C. This is high enough to see oxidation-reduction reactions, crystal growth, and the melting of some metals and minerals.

Samples also can be cooled to −100 C by using liquid N_2 and Peltier-effect devices.

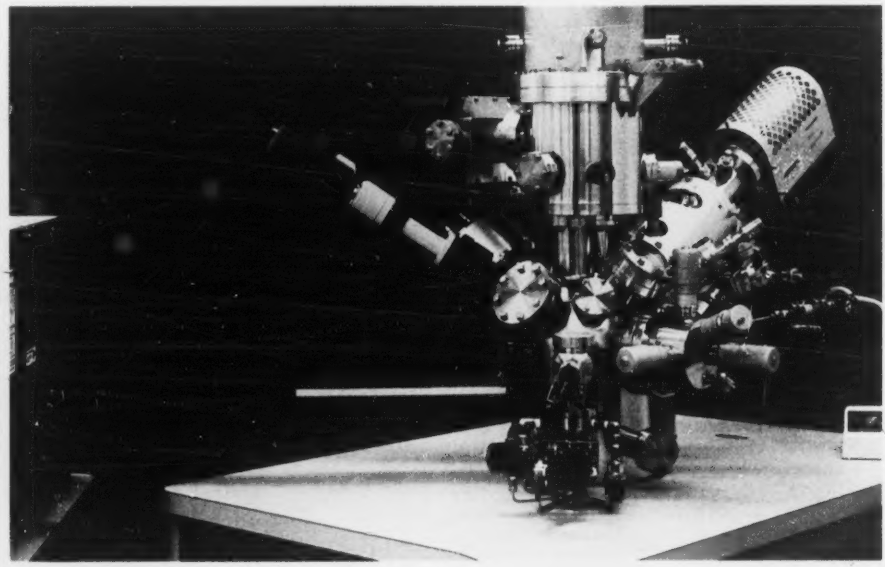
SURFACE ANALYSIS instruments are going through a maturation process that's bringing them out of the research and development stage and into use as reliable analytical tools.

"It's incredible how good some of the new instruments are now," says Charles Evans, president of the analytical service company Charles Evans & Associates, Redwood City, CA. "We have a new Auger microprobe system that hasn't been down a day in the past six months.

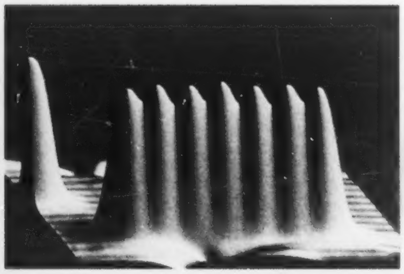
"This is such a treat compared to the maintenance required on some systems just a few years ago," he says.

The two most popular instruments in the surface analysis field—ESCA (electron spectroscopy for chemical analysis, also known as x-ray photoelectron spectroscopy) and AES (Auger electron spectroscopy) systems—have been refined over the past several years to the point where performance is approaching theoretical detection limits.

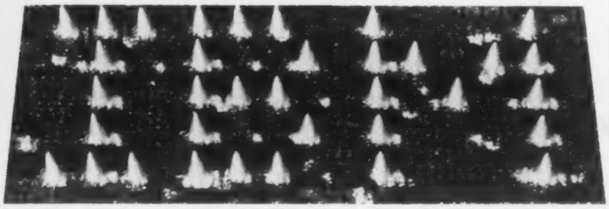
In both ESCA and AES systems, development is centered on smaller spot sizes and more computer control, says Kenneth Bomben, XPS product manager for Perkin-Elmer, Eden



To improve sensitivity, an excimer or vacuum-UV laser ionizes sputtered species in this surface analysis by laser ionization (SALI) system .



Donald Eigler, an IBM research physicist, is shown with the STM that he used to move and assemble individual atoms into patterns. The first cluster ever assembled (left) consisted of seven xenon atoms in a row, which was followed by a cluster of 35 xenon atoms arranged to spell "IBM" (below).



Prairie, MN.

Future needs for materials analyses are driving the smaller spot-size requirements. "While today's materials analyses focus on material composition, future analyses also need to focus on material structure," says Robert Cormia, manager of new markets and technology at Surface Science Laboratories, Mountain View, CA.

These new instruments will need to show you the structure of the top 100 to 200 Å of a sample nondestructively. Excessive energy input into some materials can modify the structure and change the analysis results.

To do this, the current 150-µm beam diameter on an ESCA instrument will have to be reduced to 1 µm.

Although this might require a whole new ESCA design, there is plenty of incentive to accomplish this task. Biomaterials analyses, which now account for about 30% of the surface analyses performed, are expected to expand rapidly over the next five years, says George Grobe, a senior lab analyst at Perkin-Elmer, Edison, NJ.

Secondary ion mass spectrometry (SIMS), a distant third to ESCA and AES systems in the number of installed systems, also is seeing performance and design refinements.

In quadrupole-based SIMS systems, the signal often is not large enough to use the detection limits of the SIMS technique.

To offset this limitation, there is a trend toward use of static-SIMS systems to characterize the structural information of materials, with specific emphasis on organic materials.

"We've set up a new lab that only has a static SIMS capability and it is doing quite well," says Evans.

Probably the hottest area in surface analysis systems is time-of-flight SIMS (TOF-SIMS) instruments. These systems offer better sensitivity than other surface analysis systems for detection of submonolayer materials.

However, "the data from a TOF-SIMS instrument are complicated and need an expert system for materials analyses," says Cormia.

One system that seems to be catching on uses the TXRF (total reflectance x-ray fluorescence) technique. TXRF is a refinement of conventional XRF. However, instead of irradiating the sample in the traditional mode of beaming x rays down upon the surface, the x rays in a TXRF instrument are beamed at a grazing incidence to the sample.

In doing this, the x rays don't excite the bulk of the material, they excite only the near-surface region.

These systems are good for semiconductor wafers and laser optics. They have detection limits of 10^{10} atoms/cm^2.

Other surface analysis systems, such as Rutherford backscattering spectrometry, SEM-

The hottest area in surface analysis is TOF-SIMS instruments, which offer high sensitivity to detect trace elements.

R&D Perspectives

based electron diffraction x-ray, electron-probe microanalysis, and Fourier-transform infrared, also are maturing products making inroads into specific analysis areas.

"Some systems, such as ion scattering spectroscopy, are languishing," says Evans. "If they're needed, they're usually the only technique that can do the job, but often they're not really needed."

A technique that offers the potential for improved sensitivity in surface analysis is post-ionization of sputtered neutral ions. There are four ways to do this:

- Inject the sputtered neutrals into a plasma, where they're ionized by the plasma.
- Shoot an electron beam across the surface of a sample to electron impact (ionize) the sputtered ions.
- Shoot a laser tuned to a particular wavelength, across a sample's surface to ionize a specific element coming off the sample. This system is commercialized as a SARISA (surface analysis by resonance ionization of sputtered atoms) system.
- Shoot an untuned laser across a sample's surface to ionize everything. The commercialized version of this instrument is the SALI (surface analysis by laser ionization) system. To be effective, the beam-type post-ionization techniques require flat sample surfaces.

Using a different particle

Most surface analysis techniques are either mature instruments or modifications of conventional techniques.

But one new technique is the scanning proton microprobe (see accompanying figure). The SPM technique, developed at Univ. of Oxford, England, uses a beam of protons to knock out electrons. X rays, emitted as the remaining electrons rearrange themselves, are detected and

Surface analysis instruments: Determining what the surface is

	Acronym	Detection limits	Largest sample size, ϕ (cm)	Analysis time, sec	Depth of resolution, Å	Detectable elements	Approximate equipment cost (U.S. $)
Scanning Auger microscopy/spectroscopy	SAM AES	0.1 to 1.0 at-%	20	10 to 100	50*	Lithium to uranium (conductive only)	**$150,000 to $500,000**
Electron spectroscopy for chemical analysis	ESCA (XPS)	0.1 to 1.0 at-%	20	10 to 100	50*	Lithium to uranium (chemical groups)	**$200,000 to $500,000**
Secondary ion mass spectroscopy	SIMS	0.001 to 1.0 at-%	20	100	40*	Hydrogen to uranium	**$200,000 to $700,000**
Time-of-flight secondary ion mass spectroscopy	TOF-SIMS	<1 ppm	20	10	40	Hydrogen to uranium (large org. molecules)	**$450,000 to $750,000**
Energy dispersive x-ray spectroscopy (SEM acc.)	EDX	0.5 at-%	2	100	50,000	Sodium to uranium	**$30,000 to $80,000**
Rutherford backscattering spectroscopy	RBS	1 to 10 at-%	7	900	20,000	Lithium to uranium	**$425,000 to $700,000**
Ion scattering spectroscopy	ISS	1.0 at-%	20	50	10	Lithium to uranium	**$150,000 to $350,000**
Fourier-transform infrared spectroscopy	FTIR	1.0 at-%	7	10 to 500	10,000	Organic functional groups	**$50,000 to $100,000**
X-ray fluorescence spectroscopy	XRF	0.1 to 100 ppm	20	500	2 × 10^{5}†	Magnesium to uranium	**$100,000 to $200,000**
Laser ionization mass spectroscopy	LIMS	1 to 100 ppm	20	10	20,000	Hydrogen to uranium (large org. molecules)	**$375,000 to $500,000**
Surface analysis by laser ionization	SALI	10^{-6} of monolayer	2	50	20,000	Hydrogen to uranium	**$600,000 to $800,000**

* Techniques can etch in increments of 10 Å up to a few μm. † Depth of analysis depends on the matrix.

Sources: Surface Science Laboratories, Charles Evans Associates, Perkin-Elmer Corp., *R&D Magazine*

Japan, the largest single market for surface analysis systems, is buying 10 to 15 times more ESCA systems than the U.S.

matched to material composition and structure.

While similar to XRF, SPM is more sensitive because there is very little background of unwanted x rays from other processes. Therefore, low intensity x-ray signals from low element concentrations are not obscured.

In addition to producing x rays from a sample, some of the protons bombarding the sample undergo nuclear collisions, which causes the proton itself to be backscattered out of the sample. By measuring the energy of these backscattered protons, you can measure the depth in the sample at which the collision occurred, as well as determine the nucleus involved in the collision. This means that the concentration of the elements as a function of depth into the sample can be measured.

This opens up the possibility of obtaining three-dimensional images of structures within biological cells.

Expanding foreign markets

Despite the great promise that these surface analysis techniques hold, U.S. and European researchers seem to be ignoring them. Japan currently is the largest single market for surface analysis systems.

For example, while Philips and Siemens each have about four SIMS systems, and IBM has seven, Toshiba has 15 SIMS systems, according to Stefan Daiser, ion beam systems manager for Perkin-Elmer, Eden Prairie, MN.

Japanese companies also are buying five to 10 times more ESCA systems than U.S. companies are. The only area where the U.S. still dominates is in computational-intensive Auger systems. **R&D**

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High **377** Med. **379** Low **381**

Microscopy and surface analysis business highlights

Electron microscopes sell

ABOUT 935 scanning electron microscopes and 45 transmission electron microscopes are forecast to be sold in the U.S. and Europe in 1990, according to a survey by Strategic Directions Intl., a Los Angeles-based analytical-instrument consulting firm.

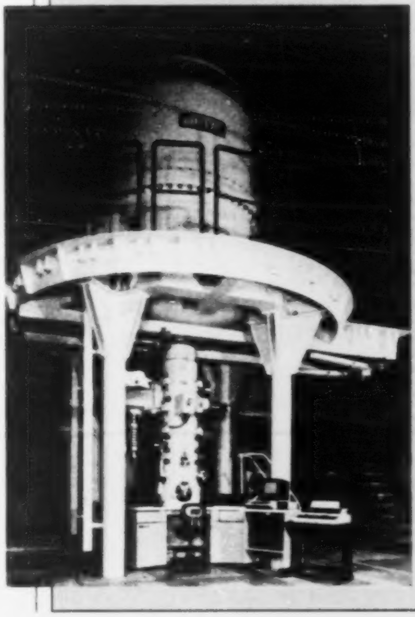
Only 50% of the SEMs in the U.S. and Europe are used in R&D applications. "SEMs are much less R&D oriented, with more systems used in quality control areas," says Lynwood Eikrem, chairman of SDI.

Japan has more patents

JAPAN, with 52 microscopy patents, edged out the U.S., with 50, for the most number of microscopy-based U.S. patents in 1989. West Germany had 17 patents. All other countries combined had 11 (19 patents were unassigned with no country of origin).

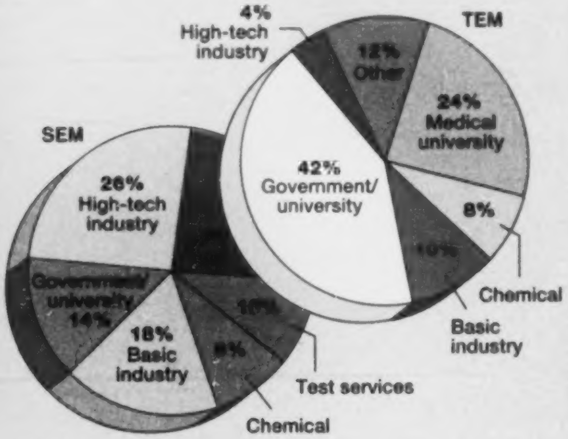
Organizations with the most microscopy patents were Olympus (12), Hitachi (11), JEOL (10), and U.S. universities (14).

For more information: MicroPatent 800/648-6787.



This 1-MV TEM at the National Center for Electron Microscopy, Berkeley, CA, has a resolution of 1.4 Å and can tilt specimens ± 40 deg.

Where electron microscopes are in the U.S.



Source: Strategic Directions Intl.

R&D

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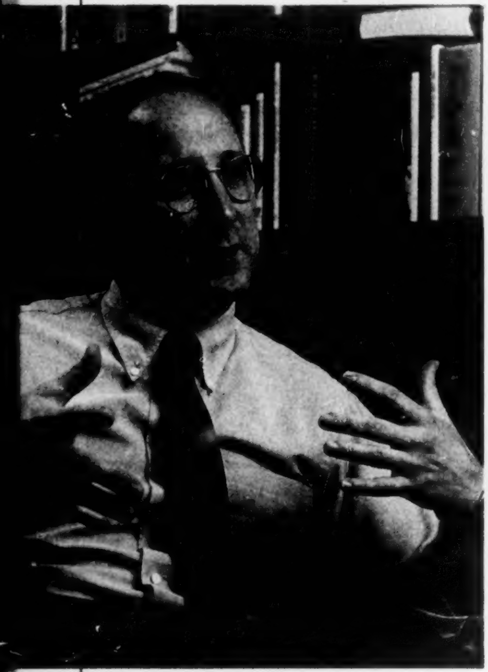

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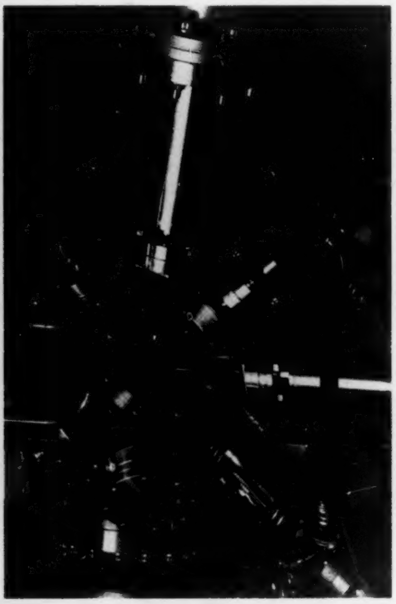

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DON'T FORGET . . .

. . . to fill out the annual *R&D* Salary Survey (p. 99). Remember, the more responses we get, the better the data. And the better the data, the easier it will be for you to argue for your next raise. Thank you. —*The Editors*

Competitive Index reaffirms loss of U.S. R&D dominance

THE COUNCIL on Competitiveness, based in Washington, DC, recently issued its third annual Competitive Index.

To the surprise of no one, it reveals that the U.S. continues to lag behind the investment, productivity, exports, and standard of living of its major economic trading partners (Canada, France, West Germany, Italy, Japan, and the UK).

In some cases, such as productivity and trade, the U.S. has improved its individual performance but still remains behind the other countries.

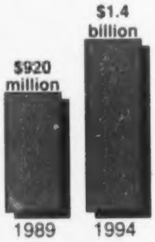
In other cases, such as in investment, the U.S. is being outperformed dramatically. "In 1989, Japan outinvested the U.S. in absolute dollars for the first time, despite Japan's GDP being only 60% of that in the U.S.," says Kent Hughes, president of the Council on Competitiveness.

Some of the index's figures, such as productivity and investment, are based on somewhat dated foreign information, particularly Italy. However, no major economic disruptions in the world economy occurred between 1986 and 1989 that would change the competitiveness relationships, says Hughes.

Domestically, no major changes in Federal support, banking policies, or industry inclinations have occurred recently that would change the current trends, portending even further erosion of U.S. R&D relative to its competitors, adds Hughes.

For a copy of the Competitive Index, 202/785-3990. ☐

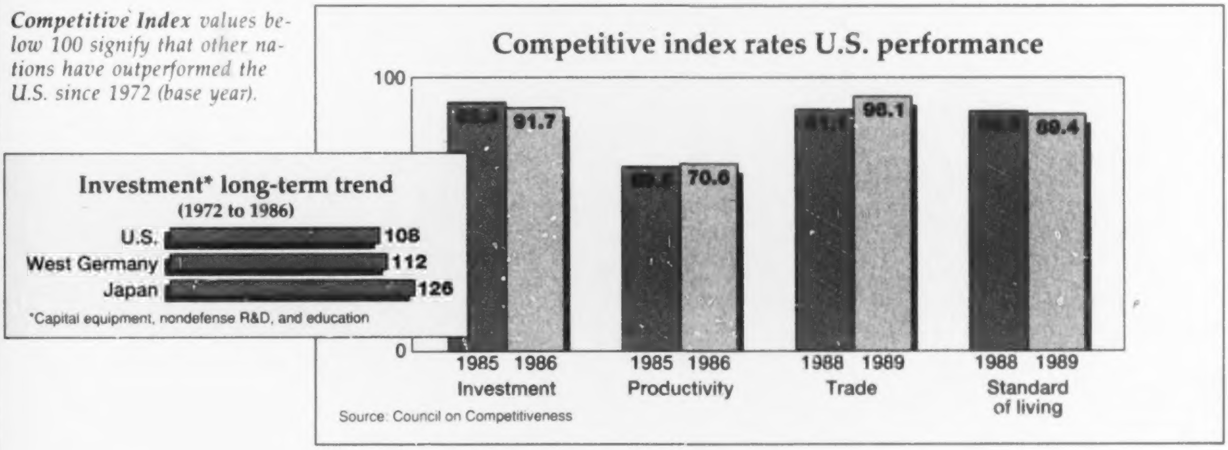
HPLC market forecast to bounce back after slump



THE recent slowdown in the high-performance liquid chromatography market is not permanent, and the market will return to an 8% growth rate during the next five years, according to David Milligan at Strategic Directions Intl., a Los Angeles-based market research firm.

Among the factors affecting the slowdown are fewer sales in biotech and governmental markets and competition from other technologies such as capillary electrophoresis.

Competitive Index values below 100 signify that other nations have outperformed the U.S. since 1972 (base year).


Competitive index rates U.S. performance

*Capital equipment, nondefense R&D, and education

Source: Council on Competitiveness

New study confirms LBOs have small effect on R&D spending

LEVERAGED BUYOUTS do not occur in R&D-intensive firms and cannot have much of an impact on [total] R&D spending in U.S. industry," says Bronwyn Hall, an assistant professor of economics at Univ. of California, Berkeley.

Hall bases this conclusion on her recently completed study of 2,500 firms involved in mergers, acquisitions, and leveraged restructurings from 1974 to 1987.

She found that only $767 million of R&D funds were involved in LBO-type transactions from 1977 to 1987, a small fraction of the $430 billion that the U.S. National Science Foundation estimates that industry spent on R&D during the same period. Even if this $767 million R&D funding had been cut drastically (nothing indicates that it was), this cutback would have had little effect on total spending, Hall says.

LBOs speed up the shrinkage of older, low-tech industries, says Hall. Typical low-tech industries that have been involved in LBOs include food, textile, auto parts and tires, and fabricated metals.

Often after an acquisition, an acquiring company will decrease its R&D funding because they need a steady cash flow to service their debt load. Hall estimates that these decreases average 0.6% and appear to be permanent in the sense that they do not become smaller even three years after the acquisition.

The general R&D spending de-

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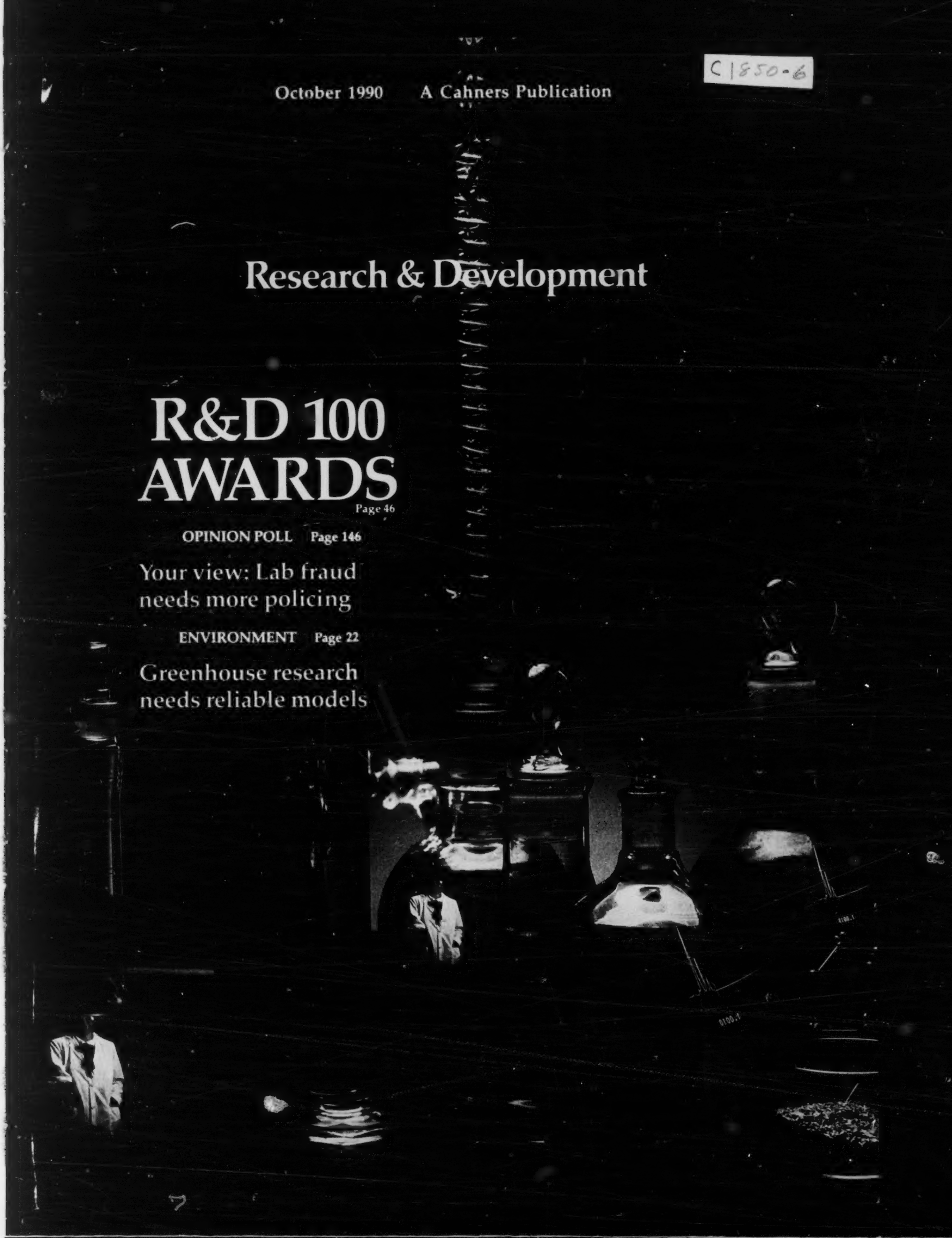

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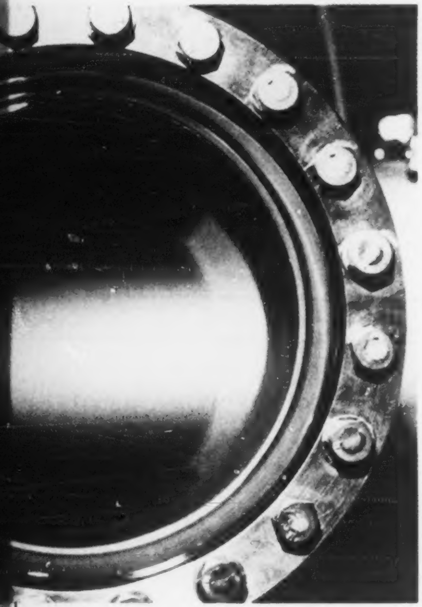
Now in its 28th year, the R&D 100 Awards program recognizes the 100 most significant new technical products of the past year. See story on page 46. (For a list of winning organizations, see page 49.) Photograph by Paul Ambrose for Catalytica Inc.



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. . . to fill out the annual *R&D* Salary Survey (p. 139). Remember, the more responses we get, the better the data. And the better the data, the easier it will be for you to argue for your next raise. Thank you. —*The Editors*

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BUSINESS

Europe pushes R&D in electronics

EUROPEAN COMPANIES are concentrating their R&D efforts in developing computers, telecommunications, and electronics, says Jack Blackburn, a London-based representative for the U.S. Dept. of Commerce.

European researchers believe that they must achieve parity in these industries with the U.S. and Japan to compete effectively in all other technological areas, Blackburn says.

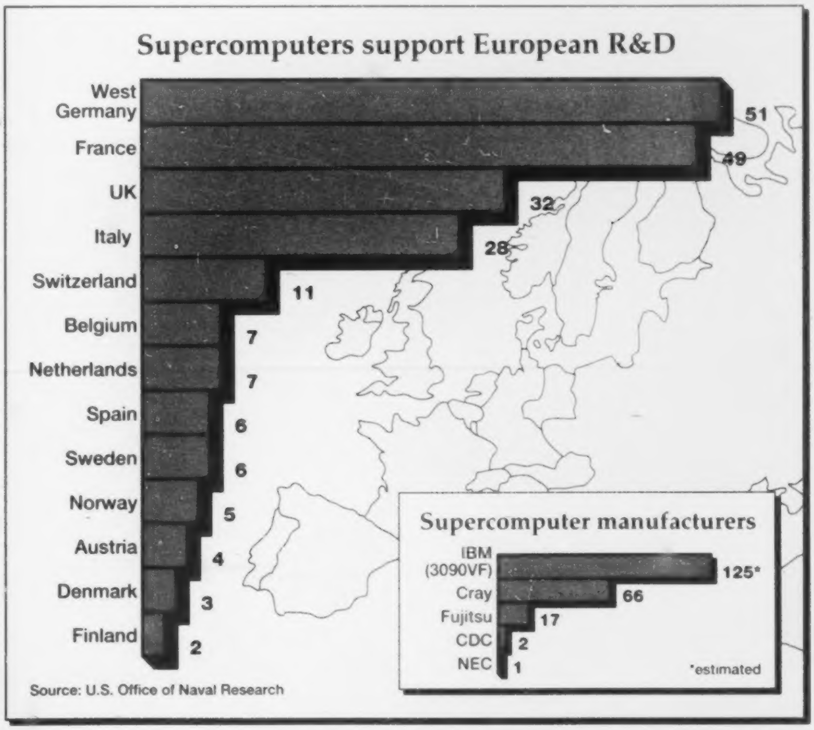
The most important trends in the European computer field are the continued use of personal computers, the use of networked systems, and the increased demand for supercomputers, says Blackburn.

About 90% of the supercomputers in Europe are U.S.-made, with the remainder coming from Japan. However, European companies are developing large parallel systems, such as Group Bull's ISIS project, Edinburgh (UK) Concurrent Supercomputer Center's 1,000 transputer system, and Esprit's (European Strategic Program for R&D in Information Technology) Genesis project.

European researchers believe that massively parallel systems will be more cost-effective than the current vector systems from IBM, Cray, and Fujitsu. They also believe that the inherent programming problems of massively parallel systems can be solved.

In contrast, IBM, Cray, and Fujitsu are continuing to develop high-speed multiple processor supercomputers, such as Cray's gallium arsenide systems. U.S. research on massively parallel computer architectures is limited to very specific applications.

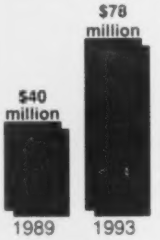
For now, demand is expected to continue for IBM and Cray supercomputers. These systems currently have 500 times more memory and 70 times more power than supercomputers had 10 years ago. —*Tim Studt*



Source: U.S. Office of Naval Research

***The European supercomputers** shown are in government and industrial research labs. Minisupercomputers and computers in sensitive military installations are not included.*

Steady growth in LIMS



Laboratory information management systems (LIMS) are forecast to grow more than 14% annually to $78 million in 1993, according to a study by Strategic Directions Intl., a Los Angeles-based market research firm.

Large computer-based LIMS are more complex and expensive than smaller networked systems but offer large storage capacities and ease of access.

Almost half of LIMS are used in R&D and more than 30% are used in organic chemistry and pharmaceutical areas.

U.S. should rethink use of defense R&D, says economist

DEFENSE R&D FUNDS can and should be used to promote civilian technology," says Robert Cohen, a visiting scholar at the Washington, DC-based Economic Policy Institute.

"Defense R&D is the largest single source of U.S. R&D funds and in spite of cuts in the military budget, it is likely to remain so for the foreseeable future," Cohen says.

Unfortunately, very little of the technology that comes out of this effort currently is transferred to the civilian economy.

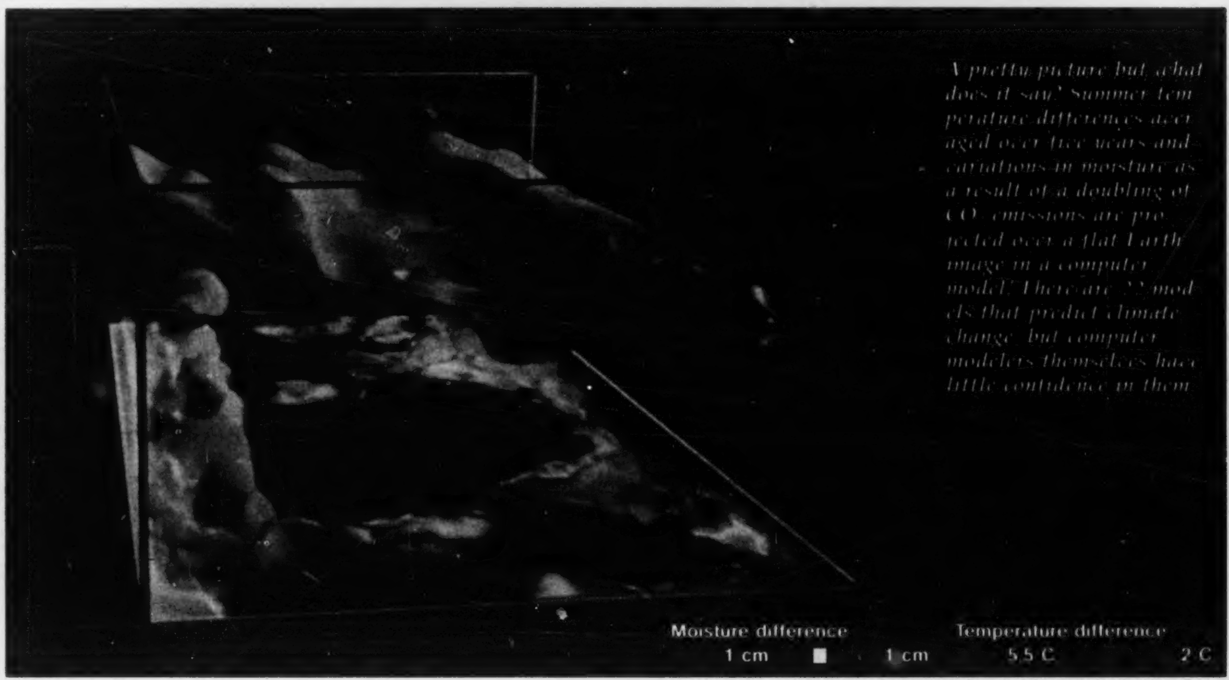
Civilian application of defense R&D is less prevalent than it was 30 years ago, when the current defense R&D structure was established, says Cohen.

The Defense Advanced Research Projects Agency (DARPA) has shown that defense R&D can be used effectively to investigate broad new technologies for use in both military and industrial applications. However, DARPA's budget is less than 3% of the total defense R&D budget.

"National security involves economics, the environment, and the education of a technologically sophisticated workforce, as well as adequate

R&D

NEWS OF SCIENCE AND TECHNOLOGY



A pretty picture but what does it say? Summer temperature differences averaged over five years and variations in moisture as a result of a doubling of CO₂ emissions are projected over a flat Earth image in a computer model. There are 22 models that predict climate change, but computer modelers themselves have little confidence in them.

Photo: U.S. National Center for Atmospheric Research/National Science Foundation

ENVIRONMENT

Models cloud climate research

SCIENTISTS trying to assess the effects of global warming are missing a key weapon in their arsenal, accurate computer models.

Without reliable computer models to simulate the effects of such things as increased CO_2 in the atmosphere, many scientists believe clean air legislation will have to be formulated without a key scientific component. Other scientists say the models really are a nonissue because what really is missing is a good theory on atmospheric dynamics.

Scientists have devised 22 models for climate change. Many of them have been developed with specific geographical regions, such as Europe, Canada, or Australia, in mind. When the various models are run in comparison to each other, the result is confusion.

"Some of the models give two to three times the warming for the same region, and some give cooling," says Lawrence Gates, a climatologist who is leading an international model comparison program based at Lawrence Livermore (CA) National Laboratory. "Some give more rain; some give less rain."

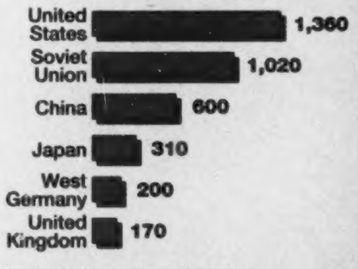
The result has been that the modelers have little confidence in the products of their own work.

"The general consensus of modelers worldwide is that the models are not reliable tools for predicting future climate," says Robert Cess, a professor of atmospheric sciences at State Univ. of New York, Stony Brook.

The problem with the models is that they are too simple to be able to simulate much of the dynamics of Earth's atmosphere. Today's computer models do not effectively handle the impact of the oceans or clouds, nor can

The largest CO_2 emitters

Millions of metric tons*



*Projected emissions for 1990

Source: Draft report of the Energy & Industry Subgroup of the Intergovernmental Panel on Climate Change

The world's largest carbon dioxide emitters are the world's industrial leaders. This means enforcement of a clean air policy could have a big impact on the economies of the U.S. and Soviet Union.

they reliably predict amounts of rainfall or understand the chaotic nature of weather systems. All of these are important components in terms of how Earth responds to pollution.

The models show general global trends, modelers say, but their resolution of 500 km^2 make it prohibitive for the models to agree on critical regional variations. Many intermodel test projects, like the one Gates heads, are being undertaken. Researchers with these programs are running the models on the same computers for the same periods of time to sort out the good and the bad of each model.

"Eventually the models will converge as we learn more about how the atmosphere works," says Warren Washington, director of the Climate & Global Dynamics Div. at the National Center for Atmospheric Research, Boulder, CO. But, he adds, that could be a never-ending project.

Most scientists agree that Earth is experiencing a general warming trend that is a product of the greenhouse effect. In the policymakers' summary of an Intergovernmental Panel on Climate Change, this worldwide group of climate researchers say global mean temperature will increase 1 C by 2025 and 3 C by the end of the next century if we continue to pump CO$_2$ into the atmosphere.

But other researchers still are waiting for observational evidence of global warming. Richard Lindzen, a professor of meteorology at Massachusetts Institute of Technology, Cambridge, says the global mean temperature has risen only 0.5 degrees, when it should have risen by 2 degrees, due to CO$_2$. What this means to Lindzen is clear.

"What is needed first of all is work on theory," Lindzen says. "Where is the theory in all of this?"

However, the more prevalent view is that the jury might still be out, but the time to act is now.

"While it is too close to call [if warming is occurring because of the greenhouse effect,] the numerical models suggest that is the way it will go," says David Erickson, a numerical researcher at Scripps Institution of Oceanography, La Jolla, CA. "Policy action should be taken before the experiment is irreversible."

—*Skip Derra*

Researcher finds cure for curing agent toxicity

George Dorsey, a scientist at Oak Ridge (TN) National Laboratory (ORNL) adjusts the flow of a reagent during the preparation of a new curing compound for polyurethane and epoxy resins. The resins are used as adhesives, coatings, encapsulants, binders, and filament windings.

The new curing agent does not appear to have the health effects associated with the widely used methylene dianiline (MDA), but it does provide viscosity and mechanical properties similar to MDA. Researchers now are trying to improve the modulus strength of the end product made with the new curing agent.

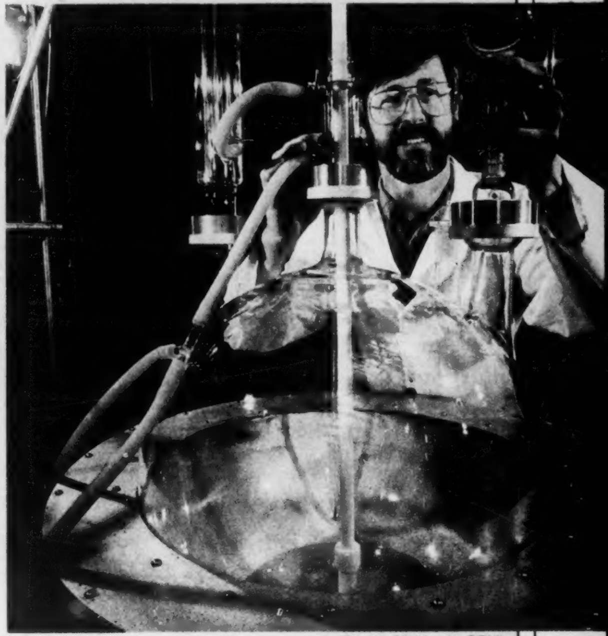


Photo: Bill Norris, ORNL

INSTRUMENTATION

New instruments help unlock clues to star formation

PLANETARY SCIENTISTS, armed with a bevy of new instruments, are taking aim at unlocking the secrets of the stars.

The researchers, from Univ. of Chicago and Washington Univ., St. Louis, are using new microanalytical techniques, including ion microprobe mass spectroscopy, to detect minute levels of materials that literally are out of this world. What the scientists have detected are three compounds—types of silicon carbide, diamond, and graphite—that they say formed outside of the solar system.

"We have found little pieces of material [in meteorites] that actually formed before the solar system formed," says Ernst Zinner, a professor of physics at Washington Univ. "The material comes from other stars."

Zinner says this supports current theory that not all of the elements that make up meteorites are vaporized into huge homogeneous mixtures before solidification. Remnants of meteorites' travels are intact, and they hold clues as to the formation of stars other than the sun.

Zinner says the measurements are made possible by new instruments that can detect very low isotopic composition levels of grains in meteorites. He adds that now that the researchers have detected the presence of the exotic materials, they want to determine if the materials reside in specific areas or are spread evenly throughout meteorites.

The researchers are testing a new method to aid this effort: it measures materials in situ, without destroying the meteorite. ☐

SPACE

Ulysses spacecraft will provide unique view of the Sun

IN HOMER'S epic poem, Ulysses' return home from the siege of Troy was held up for a long time by unexpected delays. His modern namesake, the *Ulysses* spacecraft, which will study the sun, has faced a similar fate.

Don Meyer, an assistant project manager for NASA's Jet Propulsion Laboratory, Pasadena, CA, says while the spacecraft has been delayed from an original 1983 launch date, it now is receiving preferential treatment by NASA. Meyer is optimistic that all will go well with the scheduled October launch of *Ulysses* from the shuttle *Discovery*.

"We're looking at it positively,"

R D

OPINION POLL

Fraud in the lab needs policing, say researchers

CURRENT regulations and checking systems are not sufficient to prevent fraud in industrial research, say 70% of researchers responding to a poll in the May issue of *R&D Magazine*.

More than half (56%) of the 99 respondents say they have witnessed or have knowledge of instances where data or research were changed, "fudged," or otherwise altered to produce more favorable results.

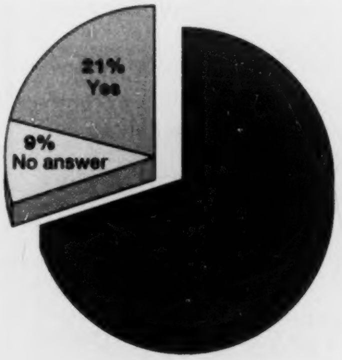
Fully 42% say they feel increased pressure to produce research results that support predetermined outcomes.

Here's what researchers say about scientific fraud. (Due to the topic's sensitive nature, names are omitted.)

I AM A RESEARCH chemist, two years out of college (BS level). Research fraud begins at the college level.

My senior physical chemistry laboratory was set up with 10 experiments. Groups of students rotated among these, theoretically doing a different experiment each week. After the third week of each quarter, having done experiments A, B, and C, no one did any more actual work. Instead, you went in and faked the work for two hours, then came out and provided your data from A, B, and C to someone else and got their data for whichever experiment you were supposed to have done. Even if you tried to do your own work, it was almost impossible because the experiments usually required the work of two people, and honest lab partners were few.

Current checking systems



Are current regulations and checking systems sufficient to prevent fraud in industrial research?

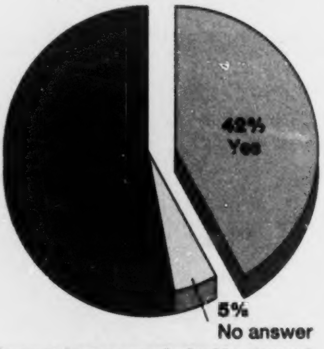
I am currently happily pursuing a master's degree in a nonscience field.

THE GREATEST pressure for fraud seems to be with research project managers changing the results of experimental lab work without the knowledge of the bench chemist who performed the work. This is done to save a manager's pet project, to gain financing, or to save face that was lost on an oversold concept.

I WORK IN AN independent nonprofit biomedical lab, and here integrity and honesty are what it's about. The quality of our research is what keeps grant money coming in.

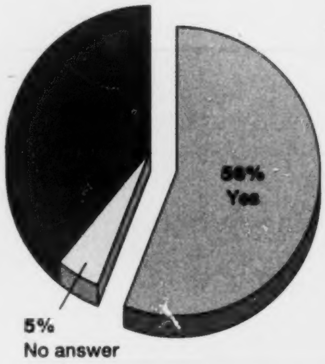
THE CONCEPT OF (more) regulations is revolting. "Checking systems" are nebulous concepts. Regardless of the magnitude or stringency of any "regulations" or "systems," they will always fall short of stopping anyone who is determined to perpetrate a fraudulent result.

Pressure to meet preset outcomes



Do you, in your work, feel increased pressure to produce research results that support predetermined outcomes?

Witnessed fraud



Have you ever witnessed or have you ever had knowledge of any instances where data or research results were changed, "fudged," or otherwise altered to produce more favorable results?

[I WITNESSED] a project manager select only "good" (but legitimate) data to report. "Bad" data were labeled "inaccurate" and not distributed. I think he was only trying to put his program in the best possible light.

We perform industrial research—about 30% pure research that can be published and 70% product research that is proprietary. There is no cross check or peer review in the 70% product R&D.

FUDGING DATA is hardly new to science. There is evidence that Isaac Newton "cleaned up" some of his optics data when it did not fit his theories. That alteration of data and suppression of alternative theories held back the development of optics. Present-day hazards of fraud are far more specialized, but in many ways, more dangerous.

Decisions concerning the future of such fields as genetic engineering and the use of new materials and fuels will be made by a population that is largely scientifically illiterate.

If we, as scientists, don't start acting responsibly and fairly in [dealing with fraud, this task] might be taken out of our hands by a distrustful public. Imagine, for example, [the situation if] a company had to have an independent laboratory verify all aspects of the development of a new product before it was allowed to manufacture that product.

I WORK FOR a very large and prestigious pharmaceutical company. I have seen it change from a company that prided itself on doing good science and producing quality products to a company that prides itself on being number one. This change in "philosophy" has created an aggressive and competitive spirit among the employees, which has encouraged misconduct.

THE MATTER OF dishonesty, cheating regarding credit to the generator of ideas in both patents and product approaches, and outright fraud is much worse than most people imagine.

There is the pressure to publish. In industry, the perceived need is to look out for number one. In academe, "peer review" favors those who have gotten a start. Honest judgments are colored by the politics of "I'll take care of you, and you take care of me." In government research grant applications, there is gross dishonesty in many instances, from flaky data to using data from outside the project to flesh out the "accomplishments."

In graduate school, my professor gave me a thesis to review. The experimental approach was faulty and badly designed, invalidating the data. He agreed on that point, but passed it. "The senior professor in the department designed the approach," he said. "I cannot say that it is not valid."

> *I wouldn't do it, and it cost me promotions and plenty of heartache.*

RESEARCH FRAUD is as rife as the biased product claims heard on television.

A famous example is that perpetrated by the head of the EPA some years ago who omitted lab results that tended to show no deleterious effects of auto exhaust on human respiratory systems.

The present hassle about the greenhouse effect is another example. . . . Not so long ago there was the fluoride swindle . . . [Now there's the] oat bran scam . . .

Research fraud is not confined to fudging results. It is just as dishonest to base conclusions on limited tests, to cast out conflicting data, or to incorporate skillfully worded disclaimers to trap the unwary, while leaving adequate legal outs.

A PRACTICE, which I find to be somewhat less than honorable, requires that we test production samples, determine their performance, then retest those samples after repainting, repolishing, or retrofitting in order to "bump the numbers" into a more favorable light.

I have complained to my superiors that the results are not representative of the end product. . . . The "enhancement" procedures are not limited to in-house tests either. Most [customers] insist on independent test reports. I was angered to learn recently that once the test reports leave our laboratory, sales and marketing

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personnel add their own "embellishments." Test data, test configurations, even the components themselves are misrepresented at will to produce a "juicier" enticement for the customer-to-be.

Approaching my supervisor has only gotten me cool defensive rationalizations that "this is the way others in our industry do it." Further attempts to squawk to the higher-ups will certainly result in my being asked to find another job [as happened with a colleague with impeccable credentials].

ONCE, WHILE WORKING for a private research institute, I observed data that had been "fudged." I had been assigned the task of reproducing some materials for a company that had paid for research and development of this material. When I was unable to reproduce these materials, I went back to the laboratory record book and found that the original raw data and proper calculations would not produce the physical properties of the materials originally reported.

Another time, I overheard a colleague suggest that test data from a particular specimen be thrown away because it did not compare favorably with the other test data.

I don't have any concrete suggestions on how to prevent cheating other than [to] eliminate the incentive to cheat. If there were other criteria for advancement and compensation of scientists, other than published papers, then perhaps cheating in research could be eliminated.

RESEARCH FRAUD, like any other kind of fraud, was, is, and will be. Only Asimov robots will not lie (perhaps!).

THE EVIL, sinful nature of man becomes apparent even amongst the high priests of scientific research. Even a PhD does not make a thief an honest man. Many up-and-coming scientists push their way up by making data look *much* better than they actually are—standard operating procedure.

CURRENT REGULATIONS and checking systems are adequate. One of the nice things about nature is that the research results obtained by cheating always eventually are discovered. Greater regulations would stifle research by increasing bureaucracy, but those who cheat still would find a way.

Almost all research is subject to an "expectation bias." If the results of an experiment confirm a hypothesis, they generally are accepted. Unexpected results usually are subjected to a great deal of examination.

To be unbiased, a researcher should spend equal time reinvestigating all experiments for experimental error, not just those that produce unexpected results.

ALTERING DATA in any way is grounds for immediate termination of employment.

HONESTY OFTEN results in the termination of employment in the pharmaceutical industry.

ANY CONCLUSIONS not supported by a thorough statistical treatment are as bad as complete fraud.

ONE DOESN'T have to actually falsify data. One can lie by omission; allow the reader to draw the wrong conclusion. My agency (Federal government) has done the above. **R&D**

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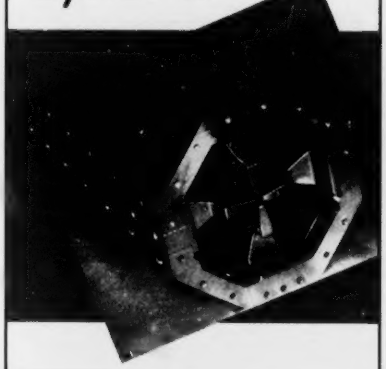

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